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PLENARY LECTURES

HYDROGEN ENERGY SYSTEM
AND COMPARISON WITH SYNTHETIC FOSSIL FUELS

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Abstract

The fuels most considered for the post petroleum and natural gas era, hydrogen (gaseous and liquid) and synthetic fluid fossil fuels, have been compared by taking into account production costs, utilization efficiencies and environmental effects. Three different cost bases have been used for hydrogen depending on the primary energy sources used in its production. The results show that hydrogen is a much more cost effective energy carrier than synthetic fossil fuels. In addition to its environmental and efficiency benefits, hydrogen causes resource conservation, and savings in transportation and capital investment. It is also shown to be a safer fuel.

1. INTRODUCTION

Presently, the earth's population is about 5 billion and is growing at the rate of 1.8% per year. However, the demand for energy is growing at a much higher rate (at about 8-10% per year), since the developing countries are trying to increase their energy consumption faster than the industrialized countries. Today, most of the energy demand is met by fossil fuels (i.e., coal, petroleum and natural gas). On the other hand, it is estimated that the world fossil fuel production, beginning with petroleum and natural gas, will soon start declining. Nonconventional energy sources, such as solar, ocean thermal, wind, current, tides, waves, thermonuclear, geothermal, etc., are being considered as possible sources of energy to meet the growing demand. However, none of these new energy sources have all the desirable qualities of petroleum and natural gas. For example, some are only intermittently available. Others are only available away from the consumption centers, and none can be used as a fuel for transportation. Therefore, it becomes necessary to find an intermediary or synthetic form of energy

which can be produced using the nonconventional primary energy sources being considered.

Many scientists and engineers believe that a hydrogen energy system could form the link between the new energy sources and the user. It is the most economical to produce, the cleanest fuel and recyclable. In the hydrogen energy system it is envisaged that hydrogen will be produced from the new non-fossil energy sources, and will be used in every application where fossil fuels are used today, In this system hydrogen is not a primary source of energy. It is an intermediary form of energy, a secondary form of energy, or an energy carrier.

This is not a new concept. More than a hundred years ago, Jules Verne, the great French visionary, through one of the characters in his book, The Mysterious Island [1],* was saying, ". . . water decomposed into its primitive elements . . . and decomposed doubtless, by electricity, which will then have become a powerful and manageable force. . . . I believe that water will one day be employed as a fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. Some day the coalrooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous caloric power. . . . I believe that when the deposits of coal are exhausted we shall heat and warm ourselves with water. Water will be the coal of the future."

Hydrogen has the most desirable properties for a fuel. It is the lightest and the cleanest fuel. It can be converted to other forms of energy more efficiently than other fuels. It is also the most abundant element in the universe. Many stars and planets are either entirely made up of hydrogen, or contain large percentages of it. For example, the most abundant element in the sun is hydrogen. The sun's energy is produced by the fusion of hydrogen atoms or nuclei into Helium. The planet Jupiter is made up of liquid and solid hydrogen. Even the interstellar space contains about one hydrogen molecule per cubic centimeter.

On the other hand, on Earth hydrogen is not abundant as a free element. It is found in natural gas in small percentages. It forms 0.2% of the atmosphere. These are very small quantities compared to the fuel needs of the world. Therefore, hydrogen must be produced using some primary energy source if it is to meet our fuel needs.

2. FOSSIL FUELS AND THEIR LIABILITIES

Presently, most (about 80%) of the world energy demand is met by fossil fuels. However, according to reliable estimates

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*Numbers in square brackets refer to references listed at the end of the report.

[2-4], the production of the fossil fuels will soon start decreasing. It is expected that the rate of production of fluid fuels--petroleum and natural gas--will reach its peak around the year 2010, and then start decreasing. If synthetic gas and gasoline can be produced from coal, the production will rise until the year 2030, and then start decreasing.

The combustion products of fossil fuels are damaging the Earth's climate and environment as outlined in many recent reports, articles and books [5-29]. An important type of pollution, air pollution, is caused mainly by fossil fuels used to obtain energy for transportation, electricity production, heat generation, etc. Because of this, in the larger cities of the world, the incidence of various respiratory diseases is increasing and the life span is decreasing. This year alone fossil fuels will be spewing some 35 billion tons of CO_2, CO, SO_2, NO_x, soot and ash into the atmosphere. Acid rains produced by fossil fuels are literally killing our lakes. Fish and aquatic plants can no longer live in the lakes of the Adirondack Park in northern New York state, because of the high level of acidity accumulated due to acid rains. The same thing is happening to the lakes of Canada and Sweden. Of course, acid rains do not fall over the lakes and oceans alone. They fall on our lands and cities as well. Studies show that acid rains are reducing farm and forestry products, and adversely affecting their quality. Acid rains also attack buildings and structures, causing corrosion and erosion. The damage to irreplaceable historical monuments may not be remediable at any cost.

For a long time, one of the main combustion products of fossil fuels, CO_2, was thought to be harmless. A recent report by Seidel and Keyes [30] blames it for the so-called "greenhouse effect." It says that the Earth's temperature has begun to rise and will continue to do so at an increasing rate. By the year 2050, it predicts mean temperature increases of 3-9°C, with the larger increases occurring in the polar regions. The report claims that this warming trend would begin altering the Earth's climate by the early 1990s. Consequently, the deserts would extend to both North and South, while agricultural lands would be displaced in the same directions and would shrink in size. Another important consequence of the rising temperatures would be the accelerated melting of the polar low caps. As a result, sea levels would be likely to rise by as much as 1 to 4 meters by the year 2100, and low-lying areas of the globe--ports, coastal cities and plains--would be flooded.

In addition to their environmental transgressions, fossil fuels have another fault. They are not distributed evenly among the countries of the world. This unequal distribution, together with the addiction to petroleum, is causing international problems between the suppliers of petroleum and the consuming nations, and an increasingly intense rivalry among the super powers in their attempts to safeguard their energy supplies in the form of petroleum.

When we consider all the detrimental effects and liabilities of petroleum and other fossil fuels, we begin to

think that we are fortunate to be running out of them. If there were an interminable supply of fossil fuels, we would eventually turn this planet into a desolate graveyard.

3. NONCONVENTIONAL ENERGY SOURCES AND THEIR SHORTCOMINGS

In order to make up for the depletion of fossil fuels and meet the growing world energy demand, several alternative and nonconventional primary energy sources are being considered and researched by scientists [31-42], such as direct solar radiation, wind energy, currents, waves, tides, ocean thermal energy, nuclear breeders, fusion reactors and geothermal energy. It may be necessary to make use of several of these primary energy sources. Of course, they do not all have to be used at the same time and/or place. Depending on the economics and availability, different mixes of the primary energies may be used in different parts of the world through different time periods.

Fossil fuels, on the other hand, have some very useful properties, which are not all shared by nonconventional energy sources. They possess concentrated energy. They are relatively light for the amount of energy contained in them. they can be transported easily using pipelines, railcars, tankers and/or trucks. They are storable. They can be stored for long periods of time without any change in their properties. However, as outlined before, fossil fuels are not renewable. It has taken nature millions of years to produce the fossil fuels which we will be consuming in one century or so.

The nonconventional energy sources, which are being considered, do not possess all the advantages of fossil fuels, although some of them, such as solar, wind and ocean-thermal, are almost unlimited and are environmentally compatible. Some are only intermittently available. For example, solar energy is only available in the daytime when the skies are clear. Even then, the intensity of solar radiation is subject to diurnal and seasonal changes. Hence, solar energy needs to be stored to meet the demand when solar radiation is not available. Some of the new energy sources are continuously available, but they are too far away from the consumption centers. For example, the best ocean-thermal energy sites are the equatorial regions of the oceans. In the case of nuclear power plants, because of the potential danger from radioactivity, it would be better to locate them away from the cities or the consumption centers.

None of the new energy sources mentioned can be used as fuel for transportation with, perhaps, the exception of nuclear energy. Nuclear energy is being used to power some ships. However, it has not, as yet, proved itself commercially. None of the new energy sources, with the exception of nuclear, is transportable or storable by itself. Some are not pollution-free, such as geothermal which brings out chemical pollutants, and nuclear which produces thermal pollution and radioactive waste.

4. HYDROGEN ENERGY SYSTEM

The above-mentioned shortcomings or drawbacks of the nonconventional energy sources point to the need for an intermediary energy system to form the link between the new primary energy sources and the energy consuming sectors or the user. In such an intermediary system, the intermediary energy form or carrier must be transportable and storable; economical to produce; and renewable and pollution-free, as far as possible. It ought to be independent of the primary energy sources used, so that even if the primary nonconventional energy sources are changed from time to time, the intermediary energy system remains intact. This would have the advantage of keeping the storage and transmission systems and conversion devices running on the intermediary (synthetic) fuel the same, even though the primary energy sources may have to be changed with geographic location and time.

All the synthetic fuels (hydrogen, methane, methanol, ethanol, ammonia, hydrazine, etc.) are candidates for the intermediary system. Among these, hydrogen meets the above prerequisites best. It is plentiful in the form of water in oceans, lakes and rivers. It is the cheapest synthetic fuel to manufacture per unit of energy stored in it. It is almost pollution-free, or the least polluting of all of the synthetic fuels. Over the last decade there have been increasing research efforts to investigate the various aspects of the hydrogen energy system and its implications. Most of the research results have been presented in the proceedings of The Hydrogen Economy Miami Energy (THEME) Conference [43] and in those of the seven World Hydrogen Energy Conferences [44-50] held to date. Books and reports by Bockris [51], Veziroglu [52], Ohta [53], Williams [54] and Skelton [55] cover hydrogen production methods and utilization in some depth.

Table I compares hydrogen (both liquid and gaseous) with gasoline and natural gas. A study of the table shows that for a given amount of energy, hydrogen weighs about one-third of the fossil fuels. But it is bulkier; for a given amount of energy, hydrogen in liquid form occupies 3.8 times the volume occupied by gasoline, and in gaseous form it occupies 3.6 times the volume occupied by natural gas. However, in practice, the volume penalty is 20-50% less, since hydrogen can be converted to other forms of energy at the user end more efficiently than fossil fuels. Its high flame speed and wide flammability limits make hydrogen a very good fuel for internal combustion engines, gas turbines and jet engines. High ignition temperature and low flame luminosity make hydrogen a safer fuel than others. It is also nonpoisonous and recyclable.

Figure 1 shows the proposed hydrogen energy system, forming the link between the nonconventional energy sources and the user [56, 57]. Hydrogen is produced from water using one or more of the nonconventional primary energy sources. During the changeover period, coal, a relatively abundant fossil fuel, could also be used for hydrogen production with some environmental benefits. Hydrogen can be produced by four main

TABLE I

PROPERTIES OF GASOLINE, NATURAL GAS AND HYDROGEN

Property	Gasoline	Natural Gas	Hydrogen
Density (gr/cm^3)	0.73	0.78×10^{-3}	0.84×10^{-4} (gas) 0.71×10^{-1} (liquid)
Boiling Point (C)	38/204	-156	-253 (20 K)
Lower Heating Value: Gravimetric (kJ/kg)	4.45×10^{4}	4.8×10^{4}	12.50×10^{4}
Volumetric (kJ/m^3)	32.0×10^{6}	37.3×10^{3}	10.4×10^{3} (gas) 8.52×10^{6} (liquid)
Stoichiometric Composition in Air (Volume %)	1.76	9.43	29.3
Flammable Limits (% in Air)	1.4 - 7.6	5 - 16	4 - 75
Flame Speed (m/sec)	0.40	0.41	3.45
Flame Temperature in Air (C)	2197	1875	2045
Ignition Temperature (C)	257	540	585
Flame Luminosity	High	Medium	Low

methods: (1) the direct thermal method, (2) the thermochemical method, (3) electrolysis, and (4) photolysis. As a result of using one of these methods, water is separated into its elements, hydrogen and oxygen. Hydrogen is then transported, stored and distributed to energy consumption sectors, where it is used in every application of fossil fuels, with the exception of cases where carbon is specifically needed. After use as fuel, hydrogen turns into water vapor (by combining with oxygen) which is recycled back to earth as rain. The oxygen produced could either be released into the atmosphere, or shipped or piped to industrial and city centers for industrial use and also for rejuvenating the polluted rivers and lakes, and in speeding up sewage treatment.

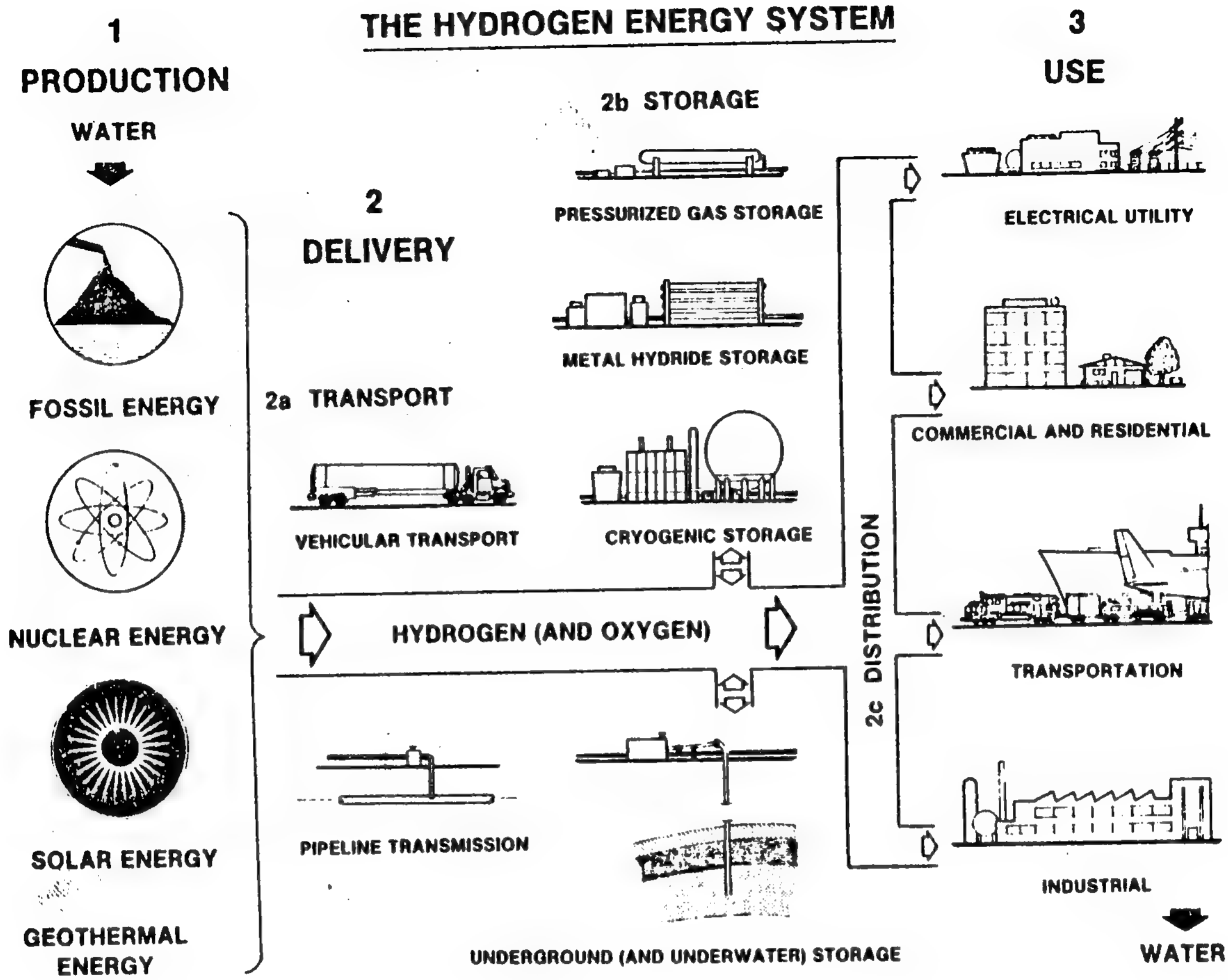

Fig. 1. Hydrogen Energy System.

Hydrogen is a very efficient energy carrier. For distances greater than 400 miles, it is cheaper to transmit energy as hydrogen through pipelines than as electricity via overhead lines. In addition, hydrogen pipelines would need very little right-of-way, take up no land area, and do away with unsightly electricity transmission lines and towers. Also, hydrogen is storable while electricity is not.

In the hydrogen energy system, it is envisaged that from the production plants or the ports, hydrogen will be transmitted by means of underground pipelines to industry, buildings and homes. There, hydrogen can be used directly for industrial processes needing heat, and for space heating and cooking. For example, the combustion of hydrogen produces steam, which is used in many industries such as the paper and chemical industries. This is an elegant and efficient way of obtaining steam. Hydrogen can be used in the smelting of iron, in lieu of coal, with untold environmental benefits. The electricity needs of industry, buildings and homes can be met by fuel cells, in

which hydrogen and oxygen combine, to produce electricity. Today, the conversion efficiency of these cells is of the order of 59-70%. It is expected that this figure will be improved upon with further research.

Because of its ideal properties as a fuel and its lightness, hydrogen is a very good fuel for transportation. In internal combustion engines, it can be converted to mechanical energy with 15 to 20% higher efficiency than fossil fuels. Additionally, hydrogen-fueled engines do not need pollution control devices and, as a result, conserve more energy. Because hydrogen is so much lighter than jet fuel, it considerably reduces the take-off weight of airplanes and consequently decreases the fuel consumption. With hydrogen, all the objections to supersonic transport are eliminated; there will be no damage to the ozone layer since the combustion product is water vapor, the engines will be quieter since they will be smaller, and the passenger per mile cost will be less due to energy conservation.

The nonconventional energy sources are distributed more evenly around the world than fossil fuels. Each country has one or more of the nonconventional energy sources available to it. Consequently, each country will be able to produce the fuel it needs as hydrogen, using the nonconventional energy source(s) it has. As a result, an important cause of international conflicts, that of energy sources (petroleum) being concentrated in a few regions of the world, will be removed, and each country will be able to speed up its economic development by producing the fuel it needs.

5. SYNTHETIC FOSSIL FUELS VERSUS HYDROGEN

Those who desire continuation of the present fossil-fuel system claim that synthetic gasoline (SynGas) and synthetic natural gas (SNG) could be manufactured through use of the vast deposits of coal, oil shale, and tar sands, or even of CO_2 from air and from limestone, when we run out of petroleum and natural gas. Consequently, hydrogen (gaseous and liquid) will be compared with synthetic natural gas and synthetic gasoline from the viewpoint of real economics; i.e., by taking into account production costs, utilization efficiencies and environmental effects, as well as such factors as resource conservation, transportation and capital investment [58-59].

5.1 Production Costs

The production costs of interest here are for the large-scale production of the synthetic fossil fuels and hydrogen, so that they may meet large-scale demands. Hydrogen can be produced by several methods, using various primary energy sources. Amongst the methods are electrolytic, thermal, thermochemical, photolytic and various "hybrid" methods. Any one of the primary energy sources, including the fossil fuels, can be used as the energy source for the production of hydrogen. As the post-fluid fossil fuel era is under consideration, the main fossil fuel resource of interest would, of course, be coal.

Table II presents the averages of large-scale production costs taken from recent literature [60-76]. In the case of hydrogen, costs are classified by the primary energy source used in production; namely, coal, hydro-power and others (direct solar, wind, waves, currents, tides, ocean thermal, nuclear, etc.), as the estimated prices also group according to this classification. All the dollar values have been brought up to 1988 US$ by assuming an average annual inflation of 8% through 1984 and 4% between 1984 and 1988.

Although gaseous hydrogen can be used in most of the applications where gaseous or liquid (and solid) fossil fuels are currently being used, there are some applications where liquid hydrogen must be used; e.g., in rocket engines for space travel and in jet engines for air transportation. Consequently, prices of liquid hydrogen must also be considered. If conventional liquefaction methods are used, the price has to be increased by about 50% [77] over that of gaseous hydrogen. However, a revolutionary liquefaction process (magnetic liquefaction) is being developed at the Los Alamos National Laboratory [78], which has a circuit efficiency of 60% as compared with only 30% in conventional systems. Preliminary studies show that the magnetic liquefaction process will need less capital investment and less maintenance than conventional systems. It then becomes reasonable to assume a 25% add-on for liquid hydrogen produced by the new method, which could be available in the 2000s.

As can be seen from Table II, the estimated production costs of coal GH_2 (gaseous hydrogen) and coal LH_2 (liquid hydrogen) are lower than those for the synthetic fossil fuels, while both GH_2 and LH_2 from other energy sources are more

TABLE II

ESTIMATED AVERAGE PRODUCTION COSTS

OF SYNTHETIC FUELS

Synthetic Fuel	Estimated Average gaseous fuel cost 1988 U.S. $/GJ	Estimated Average liquid fuel cost 1988 U.S. $/GJ
Coal H_2	7.78	9.72
Hydropower H_2	10.44	13.05
Other H_2	19.61	24.51
Synthetic fossils	8.03 (SNG)	15.65 (Syn-Gas)

expensive than the corresponding synthetic fossil fuels. In the case of hydropower hydrogen, GH_2 is more expensive than SNG, but LH_2 is cheaper than SynGas.

5.2. Utilization Efficiencies

In comparing the fuels, it is important to compare the utilization efficiencies at the user end. For utilization by the user, fuels are converted to various energy forms, such as mechanical, electrical and thermal. Studies show that in almost every instance of utilization, hydrogen can be converted to the desired energy form more efficiently than the fossil fuels (or the synthetic fossil fuels). In other words, conversion to hydrogen would result in energy conservation owing to its higher utilization efficiencies.

Investigations [79] show that, for a given number of passengers and a given payload, a subsonic jet passenger airplane would use 19% less energy, if it were to use hydrogen (liquid) instead of fossil-based jet fuel. In the case of a supersonic jet plane, the efficiency advantage of hydrogen is even greater [80]; it is 38% better than jet fuel.

Research workers [81-84] have reported a wide range (22-60%) of utilization efficiency advantages for hydrogen use in existing automobile internal combustion (IC) engines. The wide variation in the reported efficiencies originates from the fact that the lower figure applies to the engine alone, while the higher figure applies to the automobile under city driving conditions. As hydrogen can burn in lean fuel/air mixtures as well as in rich mixtures, it can cause large improvements in fuel-use efficiencies in the stop-start type city driving as compared with fossil fuels which can only burn in rich mixtures.

Hydrogen can be converted to electricity in fuel cells with much greater efficiencies than those possible in thermal power plants using fossil fuels. While conversion efficiencies for the latter are in the range of 35-38%, practical efficiencies in hydrogen fuel cells are 50-70%. In the advanced hydrogen fuel cells which are now being developed, it is expected that efficiencies will rise to 80-90%. This is an important, unique property of hydrogen, which can also increase the conversion efficiencies in transport vehicles. Even if the end use required mechanical power (such as in automobiles, buses, or trucks), hydrogen fuel cell/electric motor combinations would yield far greater conversion efficiencies than an internal combustion engine running on fossil fuels. Via a fuel cell/electric motor system, hydrogen can be converted to mechanical power more than twice as efficiently as gasoline or diesel fuel.

In some industrial, commercial and residential applications, such as in heating and cooling, fuels are converted to thermal energy. Experiments [85-86] show that hydrogen can be converted to thermal energy 24% more efficiently than fossil fuels. Gas-turbine electric power plants using liquid hydrogen may have favorable efficiency benefits if

cryogenic energy of LH_2 is converted to useful work.

Using the above-described efficiency advantages of hydrogen over fossil fuels, Table III has been constructed. On the left-hand side, it starts with 1,000 units of synthetic fossil fuel energy to meet the demands of the four main world energy-consuming sectors; namely, transportation, commercial, industrial and residential. It then divides into sub- and sub-sub-sectors. It also gives the units of fossil fuel energy needed by each sector and its components. The efficiency advantages of hydrogen over fossil fuels are given in the middle column, with the corresponding references in the next column. The following column lists the units of hydrogen energy necessary to produce the same end work as the fossil fuels. The final column is the overall summation of the hydrogen energy units required by each of the sector components. As can be seen from the final column, 736 units of hydrogen energy will suffice to do the same work as 1,000 units of fossil fuel energy. In other words, when all the applications are considered, hydrogen is about 26% more efficient than fossil fuels.

5.3. Environmental Damage

In calculating the cost of fuels to society, their environmental effects and damages must be considered. Investigations are being conducted in many parts of the world to estimate those damages. Effects of fossil fuel-produced acid rains and CO_2 on the environment were discussed earlier in this paper. Pollution elements have many dangerous effects on human beings [87]. They cause heart disease, strokes, acute respiratory infections, chronic respiratory infections, tissue destruction and cancer. Carbon monoxide, absorbed in red blood cells (forming carboxyhaemoglobin), affects a person's ability to coordinate his or her activity. The traces of lead in blood cells of children were found to be closely correlated with the amount of lead in gasoline. If inhaled for long periods--particularly in large concentrations--gasoline vapors can have damaging effects on the brain. Also to be considered are accidental suffocations, poisonings caused by CO emissions in confined spaces and loss of workdays [88-90]. Although human diseases caused by pollution are costly in terms of medical care and treatment expenses, these expenses do not cover the mental damage, human discomfort and unhappiness that may be involved.

Oil spills in seas and oceans by various kinds of ships, and particularly those caused by tanker accidents, pollute the waters and shores, causing costly damages. The oil spill from the tanker Amoco Cadiz, which in 1978 ran aground off the coast of Brittany while carrying 60 million gallons (some 228 million litres) of crude oil, caused damages in the neighborhood of $1.5 billion [11]. Another disaster, in November 1982, of the Globe Asimi while carrying 4.8 million gallons (some 18 million litres) of boiler fuel off the Baltic Sea coasts of the Soviet Union is reported to have cost $900 million. Accidents occurring at offshore oil rigs also produce substantial pollution, while ballast water habitually discharged by tankers is another menace. Also, fresh water resources suffer [91] mainly because of acid rains.

TABLE III

UTILIZATION EFFICIENCY COMPARISON BETWEEN FOSSIL FUELS AND HYDROGEN

Energy Sector	Fossil Energy Consumption by Sector (Arbitrary Units)	End-Use Energy Form/ Sub-Sector	Fossil Energy Consumption By End-Use (Arbitrary Units)	H_2 Efficiency Advantage $100(\eta_s-\eta_f)/\eta_f$ (Percentage)	Reference	H_2 Energy Consumption by End-Use (Arbitrary Units)	H_2 Energy Consumption by Sector (Arbitrary Units)
Transport	250	Road (I.C. Engine)	120	22	[84]	99	186
		Road (Fuel Cell)	25	133	[64]	11	
		Rail (Fuel Cell)	15	84	[64]	8	
		Sea (I.C. Engine)	25	22	[84]	21	
		Sea (Fuel Cell)	15	84	[64]	8	
		Air (Subsonic)	25	19	[79]	21	
		Air (Supersonic)	25	38	[80]	18	
Industrial	300	Heat	250	24	[86]	145	210
		Electricity (Fuel Cells)	50	84	[64]	65	
Commercial	150	Heat	110	24	[86]	89	111
		Electricity (Fuel Cells)	40	84	[64]	22	
Residential	300	Heat	250	24	[86]	202	229
		Electricity (Fuel Cells)	50	84	[64]	27	
World Totals:1000							736

Strip mining is yet another culprit, damaging farmlands and forests. It is reported by Taylor [27] that the U.S. Government will have to spend $19 billion (in 1982 dollars) in the period 1980-89 for land reclamation. This amount is apparently needed to correct the damages caused by strip mining. Additionally, it is estimated that, during the same period, an equal amount will be similarly spent by industry.

Detailed estimates of the fossil fuel damage on various elements of the fossil fuel damage on various elements of the biosphere are presented in Table IV. The table indicates the type of damage, reference, and the damage per unit of modified fossil fuel consumption, which is defined as the total of the petroleum and coal consumption plus one-third of the natural gas consumption (i.e., it has been assumed that the environmental damage caused by natural gas is one-third that of the liquid or solid fossil fuels).

TABLE IV

SUMMARY OF THE ESTIMATES OF THE FOSSIL FUEL DAMAGE

TYPE OF DAMAGE	DAMAGE PER UNIT OF FOSSIL FUEL ENERGY (1988 U.S. $/GJ)
1. EFFECT ON HUMANS	4.15
2. EFFECT ON FRESH WATER SOURCES & RESOURCES	2.155
3. EFFECT ON FARM PRODUCE, PLANTS & FORESTS	0.62
4. EFFECT ON ANIMALS	0.53
5. EFFECT ON BUILDINGS	0.90
6. EFFECT ON COASTS AND BEACHES	0.34
7. EFFECT OF RISING OCEAN	0.34
8. EFFECT OF STRIP MINING	0.13
9. CO_2 EFFECT ON CLIMATE	?
TOTAL:	$8.94/GJ

As can be seen from Table IV, the total environmental damage of fossil fuels is $8.94 per GJ, which is quite a large figure. This is what society pays, in addition to the market prices, for using fossil fuels. On a worldwide basis, it amounts to about US$1,744 billion, or 12.7% of the world's projected total Gross Domestic Product in 1988. It should be noted that the figure of $8.94 per GJ ought actually to be greater, as it does not include the costs of human discomfort and any induced climatic changes.

5.4. Effective Cost

In order to compare the synthetic fuels under consideration, we could define a societal (effective) cost, which takes into account the production cost, utilization efficiency and environmental cost, as follows:

$$S = (P + E)\ \eta_f/\eta_s \tag{1}$$

where S is the societal cost of the synthetic fuel per unit of energy, P the production cost, E is the environmental cost, and η_f/η_s the utilization ratio (i.e., the fossil-fuel utilization efficiency divided by the synthetic fuel utilization efficiency).

Using the above equation with the data developed earlier, Table V has been prepared to give the societal costs of the four synthetic fuels which are being compared. In the calculations

TABLE V

EFFECTIVE COST OF SYNTHETIC FUELS

Fuel		Production cost 1988 $/GJ	Environmental cost 1988 $/GJ	Utilization efficiency ratio, η_f/η_s	Effective cost 1988 $/GJ
SNG		8.03	5.96	1.0	13.98
GH_2	Coal	7.78	2.98	0.74	7.97
	Hydropower	10.44	—	0.74	7.72
	Other	19.61	—	0.74	14.51
Syn-Gas		15.65	8.94	1.0	24.59
LH_2	Coal	9.72	2.98	0.74	9.41
	Hydropower	13.05	—	0.74	9.65
	Other	24.51	—	0.74	18.14

it has been assumed that the environmental damage caused by SNG is two-thirds that of SynGas, one-third being due to the environmental damage at the coal (or other hydrocarbon) based production plant, and one-third due to the environmental damage at the user end. In the case of hydrogen obtained from coal, one-third of the environmental damage has been assessed as the environmental damage at the production plant. This is due to the fact that it is easier to control and reduce the pollutants in a large central plant that in the small distributed energy conversion devices at the user end.

It can be seen from Table V that hydropower-produced gaseous hydrogen has the lowest effective cost, and SynGas the highest effective cost. When the gaseous synthetic fuels are compared, the order--starting with the lowest effective cost--is hydropower GH_2, coal GH_2, SNG and other GH_2. When the liquid synthetic fuels are compared, the order is coal LH_2, hydropower LH_2, other LH_2 and SynGas.

5.5. Conservation and Capital Investment

In addition to the effective or real costs calculated above, the synthetic fuels could be compared with regard to the conservation which they can effect, and the capital investment they require.

In Subsection 5.2 above, it was shown that the weighted overall utilization of hydrogen is 26% better than that of fossil fuels. As a result, to produce the same end-work, the energy conversion devices become smaller if they run on hydrogen rather than on fossil fuels. For example, the generating system of a power plant, the jet engine of an airplane, the automobile engine, etc., would be smaller if they used hydrogen rather than a fossil fuel. In addition, the structures or frames to which they are attached would be smaller, as the energy-conversion devices would be lighter. Consequently, there would be savings in the material resources (such as metals, wood, plastics, etc.) needed to build the energy conversion systems, as well as in primary energy resources.

Assuming a linear relationship between the resources expended and the utilization efficiencies, the resource-consumption factor for hydrogen becomes 0.74 if that for the fossil fuels is taken as unity. In other words, if 1 unit of resources is consumed when the energy carrier is the fossil fuels, only 0.74 unit of resources would be consumed when the energy carrier is hydrogen. This is an important saving in resources; indeed, hydrogen could be labeled as the most energy- and resource-conserving fuel.

Of course, the above discussion refers to the energy conversion devices and related structures. However, the savings would propagate beyond them. For example, there would be savings in transportation costs of the resources, and also in storage costs, etc. Hence, the savings in the energy sector would produce savings in other sectors.

If the capacity of a production plant (including an energy-conversion system) is doubled, the capital investment needed does not double, but increases roughly as $2^{\frac{1}{2}}$. In other words, the capital investment is proportional to the square root of the size. Applying this to the energy-conversion plants, if one unit of capital investment is needed for a fossil-fuel using plant or device, $(0.74/1)^{\frac{1}{2}} = 0.86$ unit of capital investment will be needed for a hydrogen-using plant of similar capacity. This represents a 14% saving in capital investment in favor of hydrogen-using plants or devices.

5.6. Comparison with Real Economics

In order to compare the real economics of the post-petroleum (and natural gas) era energy systems, two possible scenarios have been assumed.

(1) The present system will continue and the energy needs will be satisfied by the use of synthetic hydrocarbons in the ratio of 50% SNG and 50% SynGas (the synthetic fossil fuel system).

(2) Alternatively, the conversion to hydrogen will take place, whereby 20% of energy needs will be met by LH_2 and 80% by GH_2, while one-half of the hydrogen will be produced by hydropower and the other half by direct solar, waves, currents, tides, ocean thermal and wind sources (solar-hydrogen system).

Table VI compares the real economics of the two energy systems. It gives the average effective costs for large-scale fuel production, resource consumption factors and the capital requirement factors. It can be seen that the solar-hydrogen system will result in a 39% saving in effective cost, will save 26% in resource consumption, and will require 14% less capital than the synthetic fossil fuel system.

6. SAFETY

Mainly because of the accident to the airship Hindenburg, there is a belief among many people that hydrogen is a dangerous fuel. On the other hand, scientific studies comparing hydrogen with other fuels show that it is one of the safest fuels [87, 92-97]. There are several reasons for this conclusion. One is the comparison of fire dangers and damages therefrom. Because of their functions, all fuels can burn, and therefore start fires. However, a hydrogen fire is less dangerous than a fossil-fuel fire, since a hydrogen flame has very low luminosity and radiates very little heat, while fossil fuel flames have higher luminosity and radiate intense heat. As a result, objects which are not inside a hydrogen flame are not affected, whereas objects which are close to fossil-fuel flames can be badly burned and damaged.

In the Hindenburg accident, there were some 100 people in the gondola of the dirigible. When the fire started, 35 jumped to the ground and died. The other 65 remained in the gondola

TABLE VI

COMPARISON OF FUELS RE REAL ECONOMICS

Energy System Scenario	Effective Cost 1988$/GJ	Resource Consumption Factor	Capital Requirement Factor
a. Synthetic Fossil-fuel System: 50% SNG + 50% SynGas	19.29 (1)	1	1
b. Solar-Hydrogen System: 20% Liquid + 80% Gaseous (½ Hydropower,½ Direct Solar, Ocean Thermal, Wind)	11.67 (0.61)	0.74	0.86

until it touched the ground. They walked out unharmed, as they were not affected by the radiation from the hydrogen flames. On the other hand, in the worst disaster of aviation history, when two jumbo jets (one of Pan Am, and the other of KLM) collided on a runway in the Canary Islands, more than 400 people died. Although most of them were not inside the flames, they were mortally burned because of the intense radiation. If these planes had been running on hydrogen, most of the passengers could have been saved.

There is another safety problem with fossil fuels: they and their combustion products are poisonous. If one drinks gasoline or breathes natural gas or combustion products of fossil fuels, the outcome can be fatal. Every year thousands of people around the world die from carbon monoxide poisoning. On the other hand, if one breathes hydrogen or its combustion product (water vapor), there are no harmful effects--both are nonpoisonous. This property of hydrogen makes it especially suitable for use in human settlements.

There is one problem with hydrogen being the lightest of all elements: it can leak more easily than gasoline or natural gas. However, today's technology is able to provide the hydrogen industry with pipes, valves, fittings and related equipment, which are manufactured to close tolerances to make them leak-proof. The U.S. National Space Administration, NASA, is the world's largest hydrogen-user. So far as we are aware, they have not had any accident of consequence related to hydrogen.

7. CONCLUSION

It has been shown that when all the factors are taken into account in comparing SNG, SynGas and Hydrogen, hydrogen comes on top in all counts. It has the highest utilization efficiency, is the most compatible fuel with the biosphere, the most cost-effective, the most energy conserving, the most resource conserving, the least capital intensive, and the safer fuel.

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Wind Flow Estimation in Complex Terrain

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ABSTRACT

The types of complex terrains and wind flow characteristics to be discussed will be defined. Field and modelling experiments at Atmospheric Environment Service (AES) will be reviewed. Guidelines for estimating wind speed in complex terrain will be described. The input requirements for the Guidelines program will be discussed and methods of extracting input data from topographic maps will be shown. Sample output will be presented. Finally, some more sophisticated models will be introduced and their results presented.

GLOSSARY

Fractional Speed-up Ratio: The ratio, $\Delta U(\Delta z)/U_o(\Delta z)$, where $\Delta U(\Delta z) = U(\Delta z) - U_o(\Delta z)$. The ratio is denoted as ΔS.

Friction Velocity: Denoted as u_* and related to the magnitude of the surface shear stress, τ, by the definition, $u_* = (\tau/\rho)^{1/2}$, where ρ is the density of the air.

Geostrophic Wind: The geostrophic wind results from a balance between the horizontal pressure gradient and Coriolis forces. It is a good approximation to the actual wind in smooth flow aloft in the atmosphere when friction and accelerations are not important [1].

Internal Boundary Layer (IBL): A boundary layer established when flow approaching over uniform terrain encounters a step change in surface conditions.

Logarithmic Wind Speed Profile: Mathematical idealization of a vertical profile of wind speed defined by $U(\Delta z) = (u_*/\kappa)\ \ln(\Delta z/z_o)$. This equation is valid for surface-layer flow over a horizontally uniform and flat surface under steady-state and neutral stratification conditions. Stratification effects are often accounted for by the addition of a term that is linear in Δz. Since u_* and κ are independent of z, the ratio of wind speeds at two heights is simply $U_2/U_1 = \ln(\Delta z_2/z_o)/\ln(\Delta z_1/z_o)$ whenever the logarithmic law applies. According to [2],

the requirement for horizontal homogeneity is fulfilled for height to fetch ratios of 1/100 and the requirement for steady state is satisfied if temporal changes in wind speed are much smaller than the mean wind speed.

Neutral Stratification: (See also Stratification). If a parcel of air that, after vertical displacement within an atmospheric layer without mixing with the surrounding air, experiences a net vertical force of zero, then the atmospheric layer is neutrally stratified. Under such conditions, the parcel will neither tend to re[illegible] to i[illegible] initial position (stable stratification) nor accelerate away from it (unstable stratifica[illegible]).

Planetary Boundary Layer (PBL): That region of the atmosphere, lying below the free atmosphere, that is directly affected by friction at the earth's surface. Also known as the Atmospheric Boundary Layer.

Roughness Length: The height above ground at which, in surf[illegible]e-layer theory, the wind speed is zero. The roughness length is the constant of integration in the surface-layer equation for wind shear in neutrally stratified flow, $dU/d\Delta z = u_*/\kappa\Delta z$, where U is wind speed,. The above equation is integrated to give the equation for the logarithmic wind speed profile.

Steady State: A state during which conditions do not change with time (i.e., partial derivatives with respect to time are zero).

Stratification: A description of the vertical stability of the atmosphere or of a layer within the atmosphere. An atmospheric layer may be stably, neutrally or unstably stratified. (See also Neutral Stratification.)

Surface Layer: The shallow layer, within the planetary boundary layer, immediately adjacent to the earth's surface, in which the frictional drag force is dominant. Typically, its depth is of the order of a few tens of metres (e.g. 20 - 100 m). The surface layer is characterized by approximately constant eddy stress and wind direction with height.

Surface-layer Theory: A theory applied in the surface layer to steady-state flow over horizontally homogeneous terrain.

Turbulence Closure: A method of closing the system of equations governing turbulent flow by expressing higher-order moments or statistics in terms of those of lower order. In first-order closure, for example, the momentum flux (or Reynolds stress) is parameterized using the vertical gradient of the mean flow, thus reducing the number of dependent variables to the number of governing equations. (See [1].)

NOTATION

- E = turbulent kinetic energy
- f = $2\Omega \sin \phi$ = Coriolis parameter
- h = height of terrain feature above upstream terrain
- L = horizontal length scale of terrain feature, defined as the distance in the upwind direction to the point where the terrain is h/2 above the upstream terrain
- ℓ = inner layer depth
- p = (subscript) prediction site
- r = (subscript) reference site
- r = distance from prediction site to roughness change in upstream direction

U_g = geostrophic wind speed
U_o = upstream wind speed
u = (subscript) upstream site
u_* = friction velocity
z_o = roughness length
ΔS = fractional speed-up ratio
ΔU_R = roughness-induced wind speed perturbation
ΔU_T = topographically-induced wind speed perturbation
Δz = height above ground
δ_I = internal boundary-layer height
ε = dissipation
κ = Von Karman's constant = 0.4
ρ = density of air
σ_w = standard deviation of vertical velocity at prediction site
τ = turbulent shear stress
ϕ = latitude (absolute value)
Ω = $7.292 \times 10^{-5}\ s^{-1}$ = angular velocity of Earth's rotation

1. INTRODUCTION

Wind flow in complex terrain is a very broad topic, involving many scales and many mechanisms. In this lecture, I will concentrate on the micro-α to meso-γ scales (0.2 - 20 km, approximately), following the terminology of [3]. I will outline how the flow is modified by hills and valleys and downstream of a change in surface roughness, but will not deal with thermal effects or variations in other surface properties. The discussion, therefore, will emphasize strong winds and near-neutral thermal stratification, situations which are of most interest for wind-energy and wind-loading applications.

2. FIELD AND MODELLING EXPERIMENTS AT AES

Since 1981, scientists at AES have undertaken a number of joint modelling-experimental studies. These include Kettles Hill, Alberta, Canada and Askervein Hill, Outer Hebrides, Scotland. Model development includes the MS3DJH/3R ([4], [5]) and MSFD [6] linear models. We have also been involved in some studies with nonlinear finite difference models [7]. Recently, a microcomputer version of MS3DJH/3R, called MS-Micro has been developed and is now available for distribution. Sample results from these models will be presented and compared with field data.

3. GUIDELINES FOR ESTIMATING WIND SPEED VARIATIONS IN COMPLEX TERRAIN

The techniques developed by [8] and [9] are useful for estimating wind speed on hilltops, ridges, escarpments, in valleys and/or downstream of a change in surface roughness. Recent extensions to the original Guidelines enable estimates to be made for rolling terrain or where the reference site (measurement site) is not upstream of the prediction site. An improvement has also been made in the calculation of the IBL height generated by a change in roughness. Turbulence intensity estimates have been added. The lecture will include definitions of the fractional speed-up ratio, the IBL height and various input parameters and will present the basic formulae.

3.1 Topographic Effects

Examples of wind flow over topographic features are shown in Figure 1. The Guidelines formulae for flow over topographic features are given by Equations (1) - (3) with the coefficients appearing in Table 1. Results

are for hill tops, valley bottoms, crests of escarpments, etc.

$$\Delta U_T = \Delta S\ U_o(\Delta z_p) \tag{1}$$

where $$\Delta S = \Delta S_{max} \exp[-A\Delta z_p/L) \tag{2}$$

with $$\Delta S_{max} = B\ h/L. \tag{3}$$

TABLE 1 Coefficients for use with Guidelines Estimates of Wind Speed Changes due to Topography

Terrain Type	A	B
2D ridges & valleys	3.0	2.0
3D hills	4.0	1.6
2D escarpments	2.5	0.8
2D rolling terrain	3.5	1.55
3D rolling terrain	4.4	1.1
Flat terrain	0.0	0.0

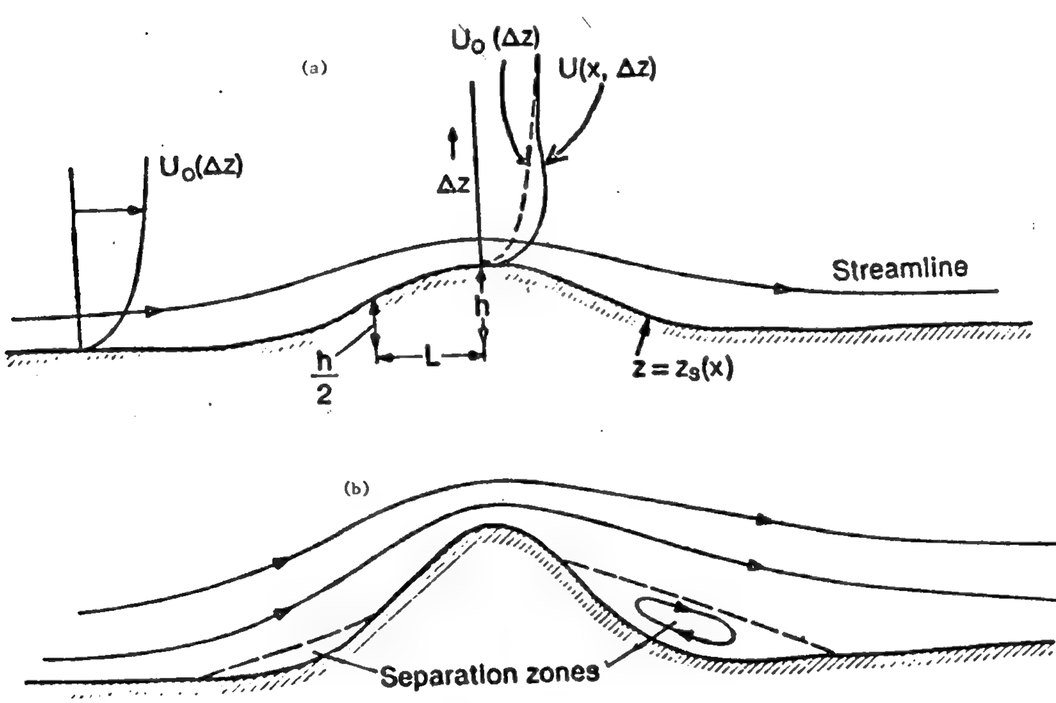

Fig. 1. Wind flow over two-dimensional hills. $U(x,\Delta z)$ is the wind speed profile at position x, $z_s(x)$ is the terrain height. (a) A gentle hill, $h/L < 0.5$ (approximately). (b) A steep hill showing flow separation.

3.2 Roughness Effects

Reference is made to Figures 2 and 3. The Guidelines formulae for flow over a change in surface roughness are given by Equations (4) - (6).

$$\Delta U_R = \{[\ln z'/\ln \delta'][\ln(z'm)/\ln(\delta'm)]-1\}U_o(\Delta z_p), \tag{4}$$

where $$r' = \{\delta'[\ln(\delta') -1] + 1\}/(F\kappa) \tag{5}$$

with $z' = \Delta z_p/z_{op}$, $r' = r/z_{op}$,

$\delta' = \delta_I/z_{op}$, $m = z_{op}/z_{ou}$,
$F = \sigma_w/u_{*p} = 1.25$.

Equation (5), from [1], is solved iteratively for δ_I by Newton's Method using as an initial guess an equation that is derived from [10]:

$$\delta' = [0.75 - 0.03 \ln(m)] (r')^{0.8} + 1. \tag{6}$$

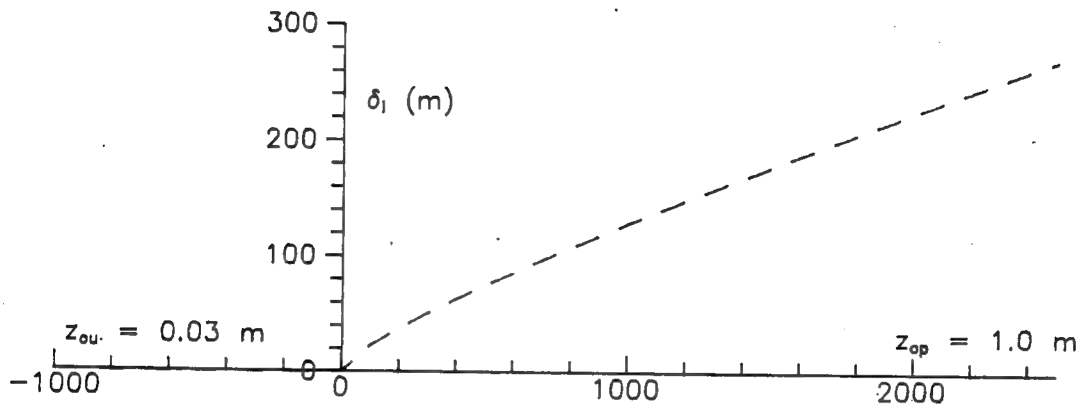

Fig. 2. Example of an IBL due to roughness change computed from Eq. (5).

3.3 Non-Ideal Reference Site

When the reference site is characterized by a roughness length, z_{or}, which is different from z_{ou}, the upstream roughness length (see Figure 4), we adopt a procedure based on the use of "Resistance Laws" for the neutrally-stratified planetary boundary layer (PBL) (see, e.g., [2], p. 34 or [11]). An equilibrium relationship between the surface friction velocity and the scalar magnitude of the (spatially-independent) geostrophic wind is assumed to exist at both upstream and reference sites. The Resistance Law is given by:

$$U_g/u_* = [(\ln(u_*/fz_o) - b)^2 + a]^{1/2}/\kappa, \tag{7}$$

where $a = 4$ and $b = 2$.

Equation (7) is assumed to be valid with u_* and z_o appropriate for either the upstream or the reference site. Given a wind speed and roughness length (z_{or}) at the reference site, the friction velocity at the reference site, u_{*r}, is computed from the logarithmic wind speed profile; then the geostrophic speed is computed from (7). Equation (7) is used a second time, inserting U_g and z_{ou} to determine u_{*u}, the friction velocity at the upstream site, by means of an iterative technique (Newton's Method). Finally, the upstream wind speed is determined from the logarithmic wind speed profile.

Combined Topographic and Roughness Effects

It is assumed that the perturbations due to topographic effects may be added to those caused by roughness change effects. Results are compared with field data in Figure 5. Figure 6 shows a plot of results from a sample run of the Guidelines program.

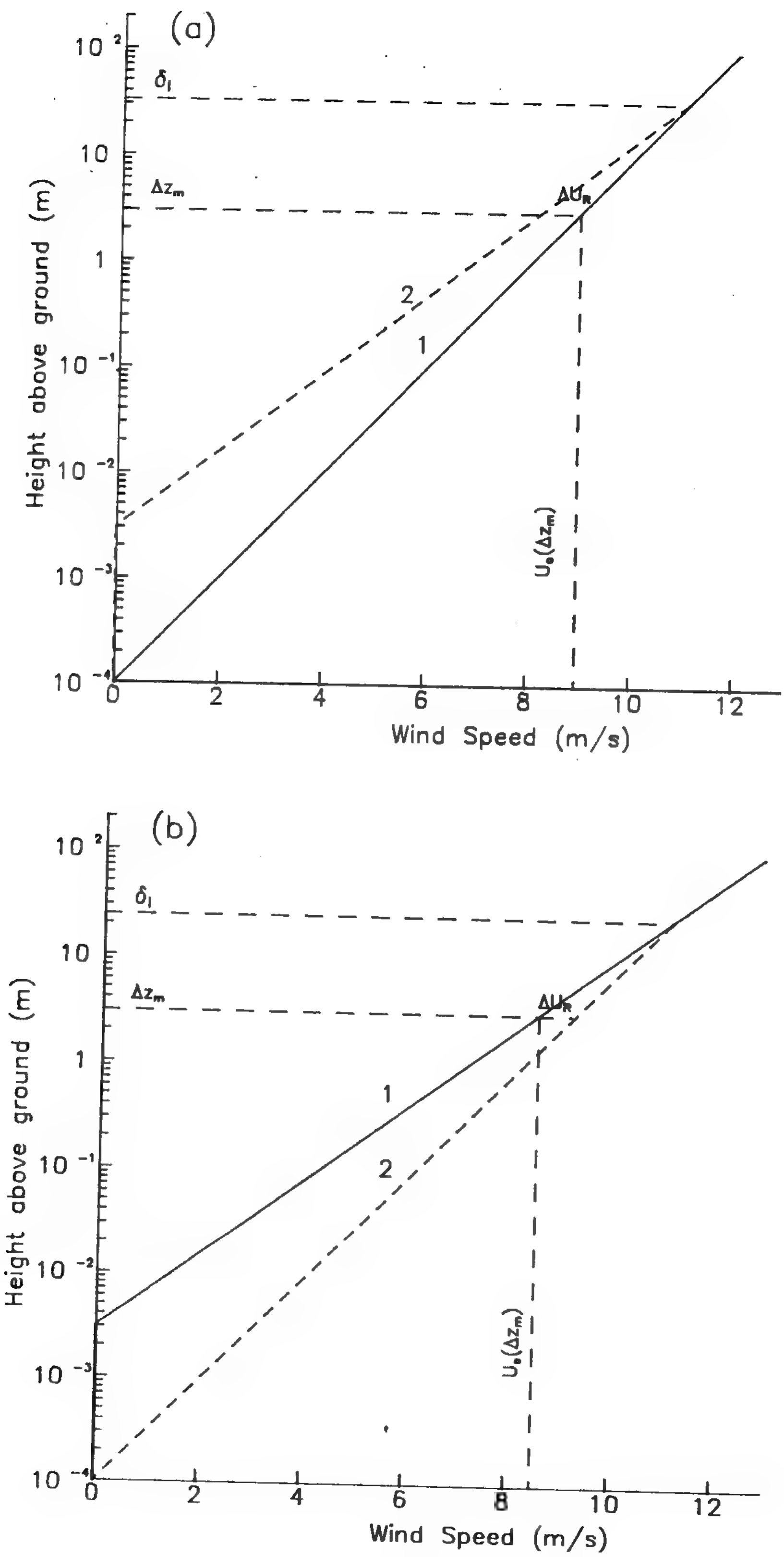

Fig. 3. Wind speed perturbation due to flow over a roughness change. Δz_m is the measurement height, (1) is the upstream profile, (2) is the profile in the IBL. (a) 'Slow-down' over smooth-to-rough change in roughness, redrawn from [8]. (b) 'Speed-up' over rough-to-smooth change in roughness.

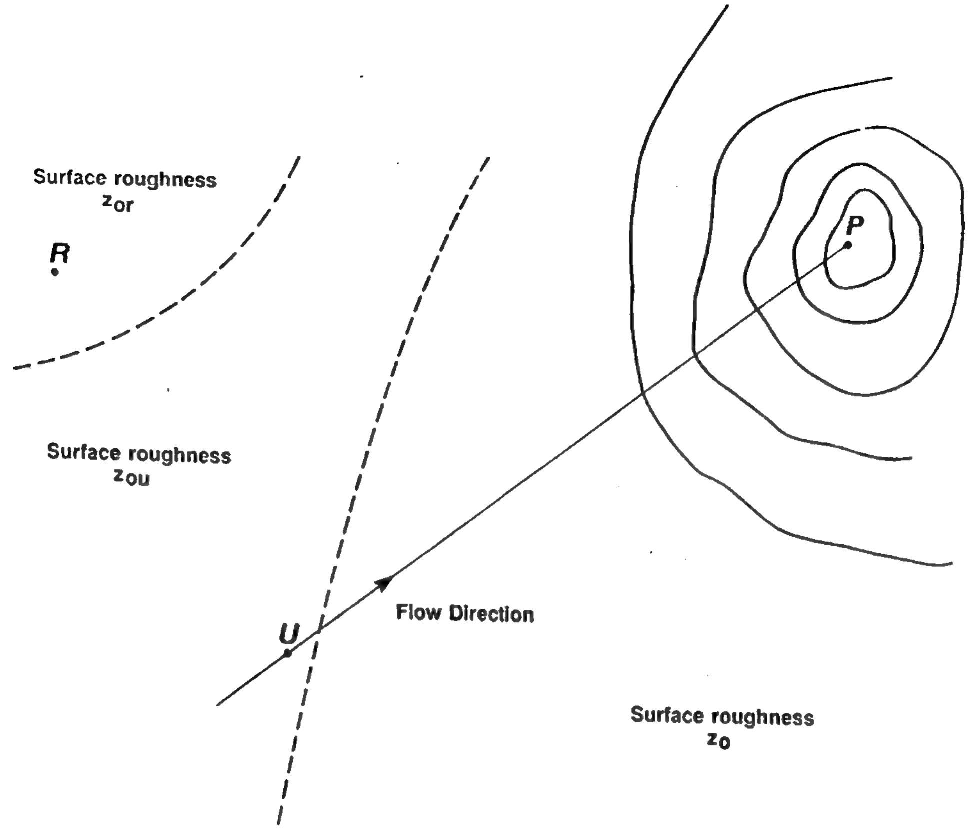

Fig. 4. Example of a topographic map illustrating a flow situation. R = reference site, U = upstream site, P = prediction site.
- - - - Roughness boundaries ______ Contour lines

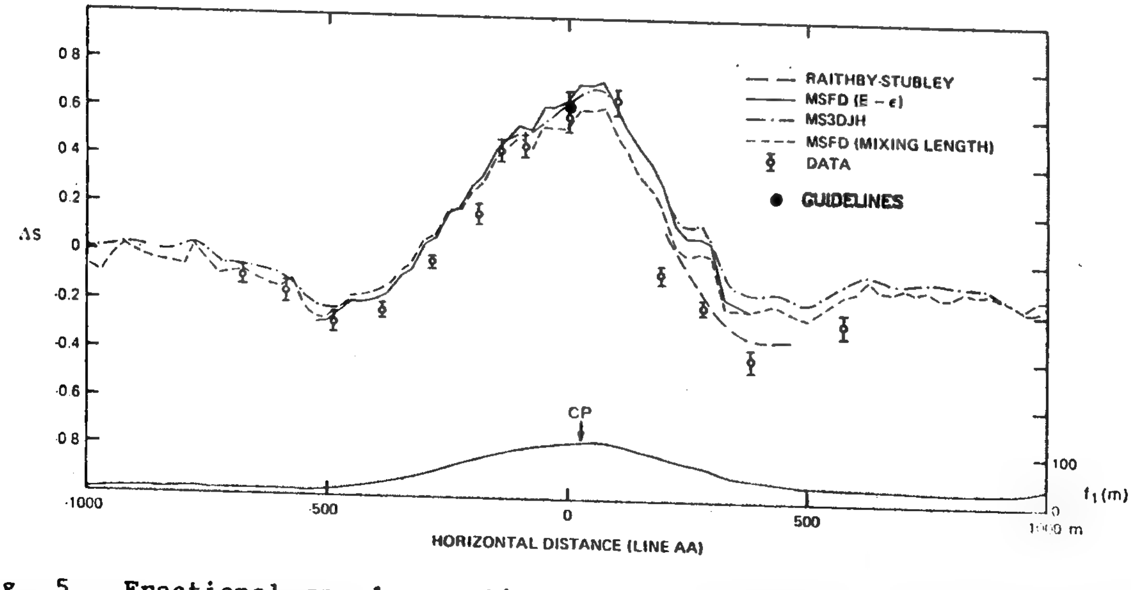

Fig. 5. Fractional speed-up ratio for flow over Askervein along line AA through the centre point, CP, of the hill. Comparison of different model results and experimental data. Wind direction is 210 degrees, Δz = 10 m, z_o = 0.03 m. Topographic cross-section, f_1, is shown without vertical exaggeration. Source: [6].

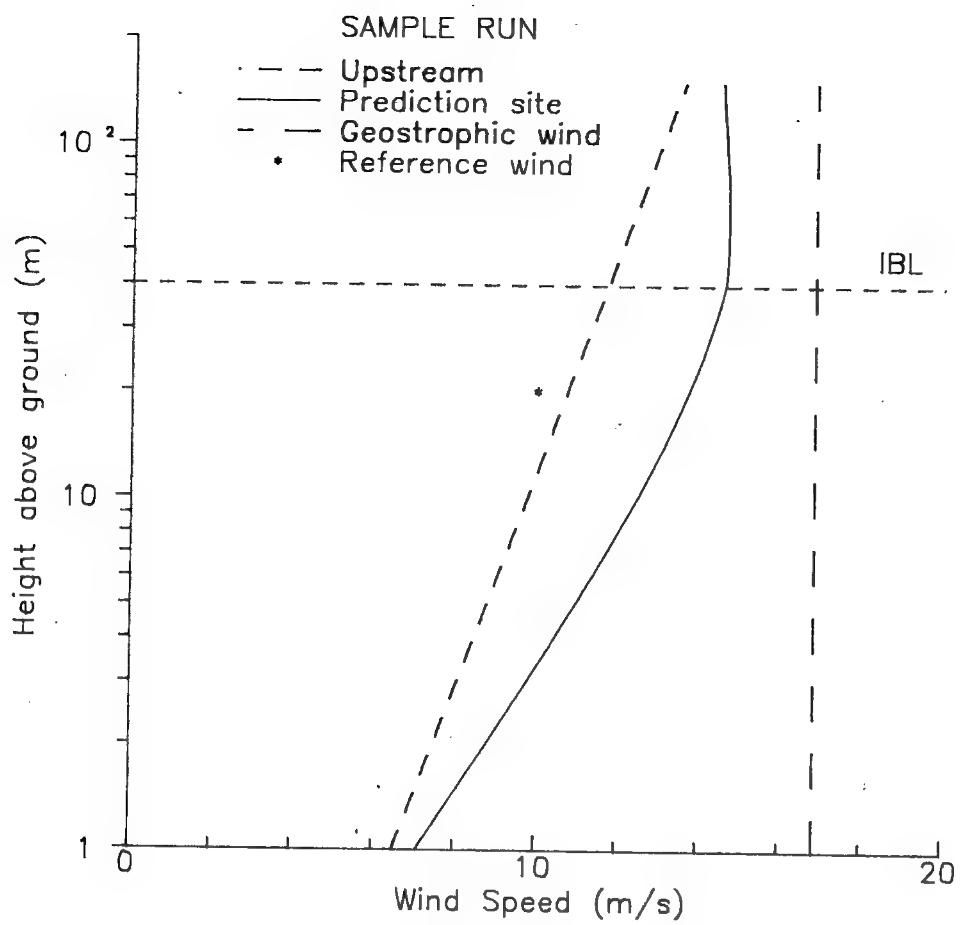

Fig. 6. Wind speed profiles for sample Guidelines calculations.

4. MORE SOPHISTICATED MODELS

A number of linearized models are available that are suitable for obtaining detailed estimates of wind speeds in complex terrain (e.g. the MS3DJH/3R model of [5]; [12]; the MSFD model of [6]; [13]; the BZ model of [14]; [15]). The model of [14] is incorporated within the framework of WASP, a microcomputer software package developed at Riso National Laboratory in Denmark. It is beyond the scope of the present lecture to discuss any of these in detail. Instead, I will outline the characteristics of the MS3DJH/3R and MSFD models (see Tables 2 and 3) and the input data they require. The former is available in both mainframe and microcomputer versions from AES. Figure 5 shows some comparisons between model results and field data for the Askervein experiment. The results of Guidelines calculations are included.

TABLE 2 Common Attributes of MS3DJH/3R and MSFD Models

1.	Surface Boundary-Layer Flow in Complex Terrain
2.	Steady-State
3.	Neutral Stratification
4.	Spatial Variations in terrain height and/or surface roughness
5.	Horizontal Scales of order 100 m to 10 km
6.	Slopes up to about 0.3 - 0.5
7.	Amplitudes of Roughness Variations of order 10^{-3} to 10^{3}
8.	Fourier Transformation in Horizontal Coordinates

TABLE 3 Differences Between MS3DJH/3R and MSFD Models

	MS3DJH/3R	MSFD
1.	TWO-LAYER MODEL Advection velocity, $U_O(\ell)$, in inner layer Inviscid outer layer	VERTICALLY CONTINUOUS MODEL Advection velocity, $U_O(\Delta z)$
2.	TURBULENCE CLOSURE Mixing Length	TURBULENCE CLOSURE $E - \varepsilon - \tau$
3.	ANALYTIC SOLUTION IN Δz	FINITE-DIFFERENCE SOLUTION IN Δz
4.	MEAN FLOW SOLUTIONS	MEAN FLOW & TURBULENCE SOLUTIONS

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INFRASTRUCTURE FOR THE PROMOTION OF THE UTILIZATION OF RENEWABLE ENERGY TECHNOLOGIES

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The present paper highlights the infrastructure and its institutional setting to promote and accelerate the utilization of renewable energy technologies in the ESCWA region. Although, in some of the countries the private sector has been promoting solar and wind energy applications in many countries of the region, the widespread utilization of renewable energy technologies is quite limited. Some of the difficulties these countries face are, lack of skilled personnel and appropriate technology, difficulty in raising funds for education, research, training, development and demonstrations and a lack of co-ordination and planning. It is suggested that regional or bilateral co-operation among countries of the regions would enable to pool financial resources and skilled manpower, and it would eliminiate duplications.

1. INTRODUCTION

Energy has become an integral part of modern society. It is perceived as a vital input into economic and social development in all countries. It is indispensable for industrial, agricultural, commercial and household use. The modern industrial era brought with it an increase in consumption of energy and changes in energy sources, from wood and coal to predominantly oil and natural gas. With the oil price adjustments since 1973 and the development of various new technologies using renewable sources of energy (RSE), there is a general trend in ESCWA countries toward diversifying energy sources, and renewable sources of energy have been considered as a component source of future energy supplies. However, despite the awareness of the inevitable depletion of hydrocarbon resources and efforts to ensure a rational use of energy, the consumption of energy continues to increase at high rates under the pressures of major construction projects and other offshoots of socio-economic development.

In accordance with General Assembly resolution 36/193, entitled "United Nations Conference on New and Renewable Sources of Energy" and adopted on 17 December 1981, the ESCWA secretariat has carried out numerous activities involving new and renewable sources of energy, with emphasis on the importance

and consequences of utilizing renewable sources of energy in this particular region, which aspires to the application of new technologies, including renewable energy technologies. Should there be a transition from conventional-based energy to a new mix of conventional and renewable sources of energy in the early part of the twenty first century, the ESCWA countries have to embark on serious research, development and demonstration in this area, and at the same time ensure that they do not lose from importing pre packaged technology, as in the case of hydrocarbon technology for which the region is still dependent on exogenous sources.

Renewable energy sources, characterized by their low energy densities but nearly universal local availability, require for their collection areas and materials al ost in proportion to the capacity size of the installation. However, because renewable energy systems are usually decentralized, they offer the advantage of providing energy options in locations where commercial sources of energy are not available, or available but at very high cost.

The development, supply and use of energy in rural and remote areas has generated great interest in most ESCWA countries, which have increased efforts to achieve some measure of rural development in order to eradicate rural poverty. Energy is playing an important role in this exercise in which new and renewable sources of energy could be utilized to fulfil subsistence and development needs in rural and remote areas. There are several applications of solar, wind and biogas in many ESCWA countries. However, so far, most of them have been dominated by research, demonstration projects and testing programmes.

It is recognized that intensive efforts are needed to overcome the difficulties facing the widespread utilization of renewable energy technologies. The most important is to establish the infrastructure and institutional setting, and these will be presented in this paper.

II. INFRASTRUCTURE REQUIRED FOR THE PROMOTION OF THE UTILIZATION OF RENEWABLE ENERGY TECHNOLOGIES

2.1 Research and Development Institutions in the ESCWA Countries

In most ESCWA countries, different activities in the field of solar and wind technologies are performed at universities, research institutes or departments within the competence of different ministries. Leading institutions of independent organizational structure that specialize in the field and that have widespread activities extending beyond research and development are the Royal Scientific Society of Jordan (RSS), the Kuwait Institute for Scientific Research (KISR), the Solar Energy Research Center (SERC) of Iraq, King Abdul Aziz City for Science and Technology (KACST), the New and Renewable Energy Authority (NAREA) of Egypt and the Egyptian Renewable Energy Development Organization (EREDO).

Most of the solar and wind energy budgets in ESCWA countries are drawn from educational budgets of universities or from budgets of governmental agencies. Some countries make special budget allocations for renewable energy research and development. These vary according to funds available and the importance attached to renewable energy.

2.2 National Projects on Solar and Wind Energy in Co-operation with International Communities

Solar energy and wind energy are clearly the two priority sources of renewable energy chosen by ESCWA countries. Interest in renewable energy in this region began in 1960 in various universities and institutions. Only after 1973 have national governments, in co-operation with major developed countries, become increasingly involved in the research and development of renewable energy.

2.3 Role of Government in Strengthening the Infrastructure

The role of government in the promotion/diffusion of mature renewable energy technologies is naturally related to the role of government in the economy generally. But these technologies should be considered in the broader context of the energy sector development.

The main activities which the government may undertake in the diffusion process are: information to consumers and manufacturers; taxes and subsidies; credit services; support of the distribution system; government participation in equipment manufacture; and raising the public awareness via different mass-media channels.

2.4 Availability of Local Materials

Promoting the use of solar and wind technologies that have been proven appropriate for the ESCWA region is dependent upon many factors. The material requirements for most solar and wind devices for current and near-term uses are available in most ESCWA countries, since any solar and wind system incorporates a number of conventional elements which are essential for the system to function.

In the case of a solar water heating system, the materials used for the solar collector, storage and heat exchanges, circulation and controls, piping networks and back-up system can be found in most local markets. The common materials used in a solar system are copper, aluminium, steel, stainless steel, galvanized steel, glass, plastic, fiberglass and wood.

The construction, operation and decommissioning of solar facilities used in the future at the multiterawatt level will create substantial requirements for materials such as steel, glass and concrete. For the photovoltaic systen, most of the material requirements are imported. In the case of wind energy conversion systems (WECS), steel, galvanized steel, aluminium, fiberglass and wood are available in the region.

2.5 Skilled Manpower Requirements

It is realized that many renewable energy technologies are particularly appropriate for small-scale and decentralized systems, and that the energy resources on which these technologies rely are abundantly available in rural areas. The rather low rate of progress achieved in the dissemination of renewable energy technologies in rural and remote areas tends to confirm that a rural energy development programme, to be successful, will depend on efforts to build and strengthen the self-reliance of local communities to devise,

implement, manage, maintain and make the most productive use of decentralized, non-conventional energy systems. Therefore, the assessment of manpower and skill needs in the renewable energy industry is a vital component of energy planning.

There is also general agreement that surveys of any manpower assessment may have to differ from country to country of the region. Decisions regarding surveys will have to be based on several factors which, inter alia, include: the importance and priority given to different energy subsectors within the entire energy development plan; energy resources and technologies which will have a bearing on the calibre of manpower required, and the gestation period required for their development and the substitution of old skills for new; and the level of training institutions and training programmes.

Currently, it is difficult to obtain detailed information on skilled manpower in renewable energy fields. Sometimes the information available is very general, referring simply to engineers, technicians, skilled, semi-skilled or unskilled workers, which are generally employed by the concerned ministries or by research institutions.

2.6 Local Manufacturing Capability

The development of solar and wind energy in the ESCWA region requires that countries be able to design and manufacture equipment to transform such sources into thermal, mechanical or electrical energy. The industrial capacity to produce such equipment exists in most of the countries in the region, albeit in varying degrees. Obviously, it will require much greater effort to increase quality as well as reduce costs. In reality, this means increasing the capacity of local engineering to improve the design of solar and wind energy equipment.

On the basis of all industrialization data collected, the capacity for instalment of solar and wind energy equipment was estimated for the various branches of industry that might eventually produce such equipment. The industries considered were heavy machinery, electricity, electronics, chemical and construction.

The following procedure has been used to obtain information on the region's potential for manufacturing such equipment:

(a) Equipment of great potential use was studied and broken down into its component parts or subsystems;

(b) After obtaining information on equipment components, an analysis was made of the industrial processes that are required both for the manufacture of components and for the production of equipment from the components;

(c) Once information was obtained on manufacturing requirements, it was possible to determine whether or not such industrial processes are potentially available within the current industrial capacity of each of the countries of the region.

It is well known that the level of sophistication of equipment or processes requires a long lead time of research and development, since the industrial processes known in some countries of the region are nonexistent in others. For example, technologies associated with the use of wind energy ar usually of intermediate sophistication, and although industrial infrastructu

exists in all countries, problems of the design and materials technology may still be encountered. On the other hand, technologies associated with the use of direct solar energy for heating, distillation, drying and greenhouses are at low levels of sophistication. However, this does not mean that little remains to be accomplished with regard to design and study of materials. Solar refrigeration and solar electricity, either by solar thermal conversion or photovoltaic conversion, are relatively sophisticated technologies in which technical and design problems continue to occur even on a worldwide level.

It is clear that the application of solar and wind energy is seen as an area of market expansion in which many major solar and wind companies are involved. Companies in Australia, Canada, France, Italy, Japan, the Federal Republic of Germany and the United States of America participate in the renewable energy market, exporting their products to the developing countries.

III. INSTITUTIONAL SETTING FOR THE APPLICATION OF SOLAR AND WIND ENERGY

3.1 Energy Planning and Policy Co-ordination

In some ESCWA countries, the lack of government and popular support for the promotion of the utilization of renewable energy has been closely linked to institutional weakness in this subsector. Institutional weakness in the energy subsector has contributed to the lack of coherent policies for the pricing, taxation and marketing of renewable energy equipment. In addition, at the sectoral level, there is a need to strengthen policy co-ordination and energy planning to evaluate future energy demand and options for management. There is also a need to establish realistic priorities among subsectors and to reconcile energy development objectives with sectoral and macro-economic constraints. In attempting to improve policy co-ordination and energy planning, the resources that are available to the government are unlikely to increase significantly. Therefore, pragmatic solutions will be needed to use scarce resources more efficiently, and these can be achieved by strengthening existing institutions rather than creating new ones.

3.2 Institutional Co-ordination

Bearing in mind that renewable energy can make a relatively limited contribution to meeting future energy requirements and that there is potential for private sector activity in this field, governments should have become an effective lead institution for renewable energy development. This institution should be part of the formal government structure and should be responsible for:

- setting priorities based on economically viable options;

- monitoring the operating agencies;

- co-ordinating external assistance for renewable energy projects;

- directing efforts in data collection.

3.3 Manpower Development and Training

(a) Manpower Development

The skilled manpower most concerned with the design, manufacturing, installation, etc., of renewable energy systems includes various branches of engineering and basic sciences--mechanical, chemical, civil, electrical and industrial engineering, and chemistry, physics and biology. Also relevant is the participation of specialists in the applied sciences related to environment, architecture, rural development and agricultural production, as well as that of specialists in the social sciences and economics.

It has been found that research studies on renewable energy have been dealt with in many of the universities and institutes of the ESCWA region. However, the lack of financial support often seriously limits the scope of these studies. The ESCWA region does have a sufficient number of qualified personnel to deal with and solve problems involving less sophisticated technologies for the use of renewable energy; however, such personnel in each invividual country cannot hope in the near future to undertake research involving high levels of sophistication. The generation of solar electricity, the production of photovoltaic cells, the production and use of hydrogen, the design of special motors that can consume renewable energy, the study of powerful wind energy conversion systems, etc., are examples of technologies to be developed in the future. They will require the co-operation of personnel with high-level, specialized scientific and technical training in more than one ESCWA country. It is also true that many countries, particularly the smallest or least developed countries, cannot take up the energy challenge individually, nor would it make sense for them to attempt to do so.

These facts lead to the conclusion that conditions for possible and fruitful co-operation should be created in the ESCWA region, both with regard to technology and the training of personnel. It appears necessary to set up advanced institutes, specialized in particular areas in which professionals from all countries may receive sound and thorough training.

At present, most developed and industrial countries are working actively to solve the energy problem with sophisticated and modern approaches. This might create in the future a new dependence on the part of ESCWA countries similar to their dependence on energy technology up to the present. The only way that is most appropriate in avoiding this problem is to initiate immediately the systematic training of scientists and professionals who will be required to carry out adequate research on the region's true energy requirements.

(b) Education

It is extremely important for the educational subsystem to create awareness among primary and secondary school and university students of the energy problem that the world will soon face, and of the importance of making economical use of depletable fossil fuels and promoting the utilization of renewable energy. A generation of young people educated to be aware of the energy problem is certainly a great asset to a country in search of competent manpower.

(c) Training

The training requirements of energy institutions should be systematically identified concurrently with manpower requirements. Each institution should

be requested to prepare a training plan covering professional and technical staff development for incorporation into the energy and education sector plans. Candidates for training should be carefully selected by the affiliated institutions. Training should be specific and on-the-job, which could resolve any problems otherwise caused by releasing suitable staff for any length of time. Overseas training should be limited to higher level staff who require specific skills for which training is not available locally. The energy institutions should also plan for adequate training provisions, including updating the knowledge of technical and professional staff.

3.4 Opportunities for Regional and International Co-operation

In areas of research and development co-operation among regional institutions involved in renewable energy could be further enhanced for manufacturing the components of solar, wind, energy and biogas systems. The stage of industrial development of the countries of the ESCWA region allows for the production of such components. This, in itself, could lead to co-operative arrangements for standardizing components, exchanging expertise, etc.., suitable for the region.

Three main potentially fruitful fields of co-operation are:

(a) Policy Issues

From the available information, it seems that falling oil prices and the resulting availablilty of relatively cheap oil have led the majority of institutions active in renewable energy research to abandon ongoing research in large-scale utilization of solar and wind energy. This situation may encourage rich oil-producing ESCWA countries to take advantage of the financial constraints faced by the technically advanced countries and to propose joint research, development and demonstration programmes. This would ensure the funding and continuity of solar and wind energy projects and the transfer of such research to the ESCWA region. Needless to say, such an approach, in addition to enhancing international co-operation enabling regional experts to share the advanced knowledge so far gained by the industrialized countries, will perhaps also result in practical contributions to regional and specific research and the development and manufacture of the new technologies.

(b) Technological Issues

The exchange of information, data and experience could be useful for ESCWA countries in the following areas:

(i) New technologies and problems related to their manufacture and commercialization;

(ii) Institutional and regulatory policies related to standardization and quality control;

(iii) Exchange of design, development and testing engineers to work in joint teams on national projects.

(c) Action-oriented Co-operation:

In this field, several countries have developed a very good bilateral and multilateral co-operation with developed countries. The action-oriented co-operation programmes are identified as follows:

(i) Establishment of regional prototype testing facilities for new technologies, especially in the field of NRSE;

(ii) Setting up of demonstration projects in high priority areas for new technologies for renewable energy;

(iii) Establishing a Regional Information Network on renewable energy;

(iv) Establishment of a regional training programme on renewable energy;

(v) Establishment of a regional technology support programme in the field of renewable energy, with micro-computer and software systems which can be used by all member countries.

IV. SUMMARY AND CONCLUSION

The present paper has highlighted the infrastructure and its institutional setting to promote and accelerate the utilization of renewable energy technologies in the ESCWA region. It has also covered the role of government and such other relevant aspects as local capability to manufacture energy equipment and to make available materials for the introduction of an endogenous renewable energy industry in the region.

In some countries, the private sector has been active in promoting solar and wind applications. However, in spite of the successful accomplishment of some commercialized energy equipment and some demonstration/pilot projects, in many countries of the region the widespread utilization of renewable energy technologies is quite limited. Especially lacking is a clear perception of the various technical, economic, social and environmental implications of their applications in most rural and remote areas. These must be investigated before such technologies are implemented. • In the long run, the ESCWA countries face numerous difficulties in promoting the utilization and development of solar and wind technologies. Some may be identified as follows:

(a) Inadequacy of information and data resource assessment and on renewable energy technology;

(b) Lack of know-how and limited technical capabilities;

(c) Lack of appropriate national policies regarding renewable sources of energy in long-term energy planning and the necessity of establishing adequate institutional infrastructures for the management and operation of solar and wind systems.

(d) Lack of financial resources for research, development and demonstration.

It is well known that for use for experimental purposes, some ESCWA countries are particularly attracted to the sophisticatred renewable energy equipment developed in the industrialized countries. However, the adaptation of this kind of equipment in any given country is dependent on that country's climatic conditions, suitability of natural resources, and skilled manpower for operating, maintaining and repairing. Therefore, a close co-ordination of research, development and demonstration programmes is needed to promote the development of indigenous renewable energy industries already in place in a

number of ESCWA countries.

From the above observations, it seems that the main problems facing ESCWA countries in the development of solar and wind energy fall into the following three categories:

(a) Lack of skilled personnel and appropriate technology;

(b) Difficulty in raising the funds required for support activities (resource evaluation, education and training, research, development and demonstration) and investment;

(c) The need for co-ordination and planning of the action to be taken.

Regional or bilateral co-operation among countries of the region is another step in the right direction to develop and promote the utilization of renewable energy. Its establishment would eliminate duplication and pool financial resources and skilled manpower, which are scarcely available in most of the relevant countries.

Although some solar and wind energy equipment is costly and site specific at the present time, still its development will help increasingly to meet the needs of rural and remote areas of the region. By developing the locally available renewable sources of energy, countries of the region will be able to improve the standard and quality of life of their people.

A NEW, SIMPLIFIED, WATER-PUMPING WIND TURBINE

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ABSTRACT

A description is given of a new, simplified, form of water-pumping wind turbine incorporating four non-conventional design features. The prototype, which has a rotor diameter of 4.9m, is provided with what has been termed a perimeter-bladed water-pumping wind turbine rotor which is a special low-speed version of the delta-wing bladed water pumping wind-turbine rotor developed at the University of Calgary during the past decade. It is explained that the relatively low rotational speed of the perimeter-bladed rotor allows the speed reduction gearbox of conventional machines to be eliminated. Other special design features are; a tower configuration to facilitate assembly without the use of a crane, a counterbalanced pump to minimise the cut-in wind speed and a simplified manual pull-out mechanism.

NOMENCLATURE

C_P = Power coefficient: (Turbine Power) $/(\frac{1}{2}PU_\infty{}^2S)$
C_T = Torque coefficient: $2C_P/\lambda$
d = Rotor diameter of conventional turbine
D = Rotor diameter of enlarged turbine
m = Number of blades in rotor of diameter d
n = Diameter ratio D/d
S = Projected area of turbine rotor
U_∞ = Free-stream (wind) velocity
λ = Tip-speed ratio of turbine
P = Ambient density

Subscripts

1 Refers to perimeter-bladed turbine of diameter D
2 Refers to conventional turbine of diameter d

1. INTRODUCTION

Over the past decade a particularly efficient form of water-pumping wind-turbine rotor has been developed at The University of Calgary. This rotor, shown diagrammatically in Fig. 1, which employs blades of delta-wing

like planform equipped with flaps, combines the features of maximum torque at zero rotor speed, an important characteristic for water-pumping applications, and the capability of achieving a maximum power coefficient in excess of 0.4. The delta-bladed turbine, or delta-turbine, has been tested extensively in both model form and in full scale: a summary of this work is available [1].

A problem that arises where a small delta-turbine is coupled to a reciprocating pump, particularly of the deep-well type, is the need for a speed reducer interposed between the rotor shaft and the pump-rod. This problem exists even with a conventional multi-bladed rotor; a delta-turbine runs approximately twice as fast as a conventional rotor with a runaway tip speed ratio of approximately 3.2 with the maximum power coefficient occuring at a tip-speed ratio of about 1.7. The speed reducer is, of course, a complication when a very simple water-pumping wind turbine is being considered. The use of a reciprocating pump is particularly desirable in a simple system because of an inherent simplicity and also the ease with which the wearing parts, primarily the flap valves and the cup-washer type piston-seal can be replaced, at low cost, in the field. A reciprocating piston type pump also appears to be as efficient, if not more efficient, than most of the other forms of pump available [2]. Energy conversion efficiencies (ideal work done on the water divided by mechanical work input) of approximately 0.8 have been demonstrated in practice [1].

Comparatively recently a revised form of delta-turbine has been developed in which the blading is placed at a much greater radius than would normally be used. This results in a rotor featuring a relatively large number of small delta-wing like blades concentrated at the rotor perimeter. Rotors of this type, termed perimeter-bladed rotors, are characterised by operating sufficiently slowly to drive directly, without the use of reduction gearing, a reciprocating water-pump of moderate stroke without the maximum acceleration of the pump-rod approaching, or worse exceeding, that due to gravity. Excessive pump-rod acceleration imposed by the driving mechanism results in attempts to push on the slender pump-rod to accelerate the pump plunger down the pump cylinder on the down-stroke instead of allowing the action of gravity to provide the required initial acceleration.

A prototype water-pumping wind turbine has been designed and fabricated incorporating a perimeter-bladed rotor and several other unusual features. The rotor diameter is 4.9m (16 ft).

2. PERIMETER-BLADED ROTOR

The principle of the perimeter-bladed rotor concept has been described in detail elsewhere [2] hence only the main features of perimeter-blading will be discussed here. Figure 2 shows, diagrammatically, a comparison of a conventional rotor design with a perimeter-bladed rotor of n times the diameter of the conventional form. As implied in the diagram for individual blades to have similar geometries, and for both rotors to have equal total blade areas, the number of blades required for the perimeter bladed configuration can be shown to be n^2 m where m is the number of blades employed in the conventional rotor. If both rotors are to be of equal power, a realistic proposition which merely implies that the blade surface area is used equally effectively in both rotors, then it can be shown that where subscript 1 applies to the perimeter bladed rotor and subscript 2 to the conventional rotor:

$$C_{P1} = C_{P2} / n^2 \qquad (1)$$

This simply expresses the consequence of the n^2 greater projected frontal area of the perimeter bladed rotor combined with the similarity of blade geometries and total blade areas.

It can also be shown that the conventional rotor geared down by a ratio of 2n produces the same output torque and rotational speed as the perimeter-bladed rotor without, for the latter, the provision of any reduction gearing. Thus for a representative value of $n = 2$, for example, a perimeter-bladed rotor of double the diameter of a conventional rotor can be expected, to a first approximation for comparable operating conditions, to rotate at one quarter the speed and also have a maximum power coefficient one quarter that of the conventional form and yet make equally effective use of the blade area provided. The torque of the perimeter bladed rotor is approximately four times that of the conventional rotor.

3. ROTOR PERFORMANCE

The performance of a dynamometer equipped model wind-turbine rotor subjected to wind-tunnel tests is presented in Figure 3. The dotted curve represents the corresponding expected full-scale performance obtained by applying a Reynolds number correction. The Reynolds number correction was derived from earlier extensive testing of model and full-scale delta-turbines [3]. A comparison of experimentally obtained and predicted performances of the same, 24 bladed, perimeter-bladed turbine is presented in Fig. 4. Whilst the prediction procedure, based upon the performance of a single blade, under-predicts the starting torque it represents fairly well the main features of the performance characteristics of the perimeter-bladed rotor the design of which was based upon an n value of approximately 2.

Fig. 5 presents results obtained from wind-tunnel tests carried out on a model 32 bladed rotor equipped with vortex flaps on the blade leading edges; these have been shown to contribute to an increase of staring torque [4]. The increase in the number of blades also increases starting torque relative to the 24 bladed rotor. It can be seen that the modifications incorporated in the version of the rotor represented in Fig. 5 nearly doubles the starting torque, whilst slightly reducing the runaway tip speed ratio, relative to the performances presented in Fig. 3 and 4. The prototype turbine was provided with a 32 bladed rotor the expected full-scale performance of which is represented by the dotted curve of Fig. 5. An indication of the geometrical arrangement of the prototype rotor is given in Fig. 6.

4. TOWER DESIGN

The tower of the prototype turbine was constructed primarily from steel angle section material joined by bolting. This well known technique ensures that the tower is assembled from comparatively small components that can be transported fairly easily. The tower which has a height of 8.2m, is of the so called wide-spread type. This helps to minimise foundation uplift loads and also makes it possible to erect the tower over manually-dug wells, if need be, which are normally of relatively large dimensions. The space-frame tower will also serve as a gantry, or derrick, when withdrawing the pump for servicing.

The tower is designed to be suitable for piecemeal erection, from the ground upwards, without the need for a crane. An unusual feature of the tower is provision of a top section which is arranged to slide along one sloping face of the tower. The top section carries the head of the machine and, consequently, it is possible to assemble the head, tail and rotor, also

without using a crane, at a height of only about 2m above ground. The whole assembly is then slid up the tower, on the special tower top section, by means of a simple hand winch. The hand winch can also be used for withdrawing the pump for servicing. Figure 7, a diagram of the complete machine, shows also the lower position (chain-dotted lines) of the tower top section.

5. COUNTERBALANCING

In order to minimise the starting torque required from the turbine rotor the pump is counterbalanced. The counterbalance consists of a weight attached to a rocking beam. The rocking beam is actuated from the rotor shaft by a simple crank and connecting rod mechanism. The pump is also coupled to the rocking beam on the opposite side of the beam fulcrum to the counterbalance location. The counterbalance balances the weight of the pump rod and plunger, less the force due to bouyancy, plus half of the pumping load. This reduces, by more than 50%, the maximum rotor torque at start-up that would otherwise be required. Under running conditions the action of the counterbalance is relatively unimportant since the rotor itself acts as a flywheel. The inertia forces resulting from the presence of the countermass are relatively small since the maximum acceleration of this component is small. Figure 8 is a view of the machine looking downwind: the rocking beam and counterbalance are clearly visible. It can be seen from Fig. 8 that the axis of the rotor is offset laterally from the yaw axis. This is a common provision on water-pumping wind turbines to ensure automatic furling under high-wind conditions.

6. PULL-OFF ARRANGEMENT

Another unusual feature of the simplified water-pumper is the provision of a manual pull-off arrangement operated from a cable suspended from the tail of the machine. This arrangement eliminates the complications involved in connecting the pull-off cable through the hollow yaw pivot as is commonly the case with most water-pumpers. The complications avoided involve the provision of internal and external sliding collars to permit yaw to occur with respect to the portion of the pull-off system attached to the tower. In the simplified system a weight is hung from the handle attached to the pull-off cable to furl the machine when it is to be shut down manually. Past experience with a cable attached, permanently, to the tail of a wind-turbine indicates that such an arrangement is operationally satisfactory. The pull-off cable is visible in Fig. 7. Figure 9 is a plan view showing more of the operational principle involved.

7. PREDICTED PUMPING PERFORMANCE

The prototype water-pumper is scheduled to be tested, for both performance and endurance, at the Lethbridge, Alberta, Canada, Wind Test Site. This site is specially equipped to handle the testing of wind-driven water-pumpers. The Lethbridge site, which is approximately 1000m above sea level, is normally arranged for water lifts of approximately 5.5m. The predicted pump-performance characteristic, Fig. 10, has been evaluated on the basis of the prevailing test site conditions. The water flow rate is, of course, expected to vary inversely with water lift, for a prescribed pump efficiency, provided the pump cylinder bore is adjusted accordingly as indicated in Fig. 11. The stroke of the prototype unit, 165mm, is independent of well depth.

8. DESIGN PHILOSOPHY

The prototype unit which was in large measure designed by the writer was fabricated by Dutch Industries Limited, Regina, Saskatchewan, Canada with the ultimate intent of proceeding to commercial production after successful completion of trials. The possibility of commercial production implied that factors other than those merely associated with demonstrating the perimeter-bladed turbine concept had to be taken into account. The essential aim of the design was to produce an inherently simple, robust, machine with an adequate performance. An additional consideration was that the machine be assemblable, without the need for a crane, from relatively small easily transported and handled components.

The bearings used in the prototype are commercially available units of the ball, and roller, type, grease lubricated, equipped with outward-opening seals. The use of outward-opening seals ensures that over-lubrication does not cause seal damage. It is expected, based on several years of past experience with similar systems, that annual greasing of bearings will be the only maintenance normally required. Long bearing lives are expected due to the relatively low bearing loads.

An attempt was made to minimise the risk of inducing fatigue failures by careful control of stress levels and the avoidance of stress concentrators. Care was also taken to maintain very low stress levels in the regions of welds subjected to cyclic or random loadings.

9. CONCLUSIONS

A description has been given of the prototype of a simplified form of water-pumping wind turbine. In particular the four non-conventional design features incorporated in the prototype were identified and described. These are:

a) the perimeter-bladed rotor which was shown, at the price of longer than conventional spokes, to eliminate the need for reduction gearing,
b) an inclined-plane type apparatus, integrated into the tower structure, for raising the head-rotor-tail assembly,
c) the use of a counterbalanced pump to maximise, for a prescribed turbine rotor and cut-in wind speed, the size of pump that can be driven,
d) a simplified manual pull-out, or furling, arrangement that avoids sliding collars etc. found, in the vicinity of the yaw bearing assembly, on most conventional wind-driven water-pumps.

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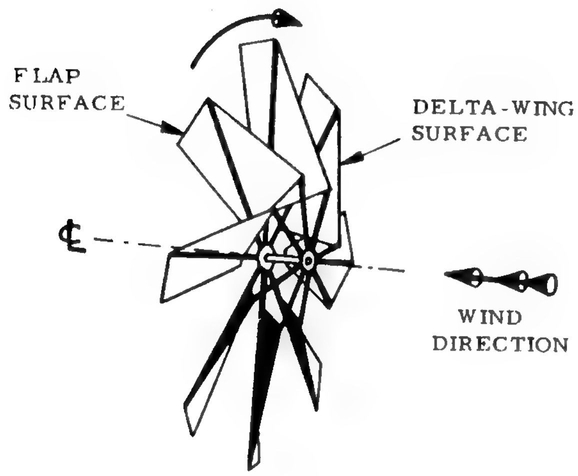

FIG. 1 A TYPICAL, EIGHT-BLADED, DELTA-TURBINE (DIAGRAMMATIC)

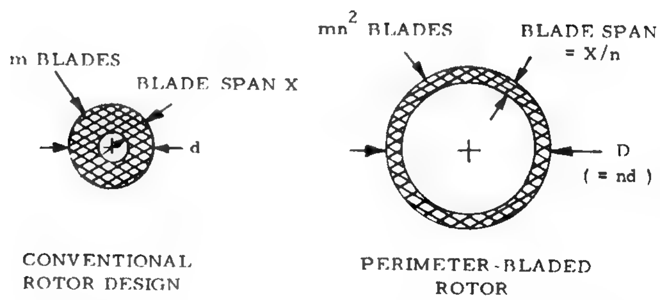

FIG. 2 COMPARISON OF CONVENTIONAL WITH CORRESPONDING PERIMETER-BLADED TURBINE ROTOR (DIAGRAMMATIC)

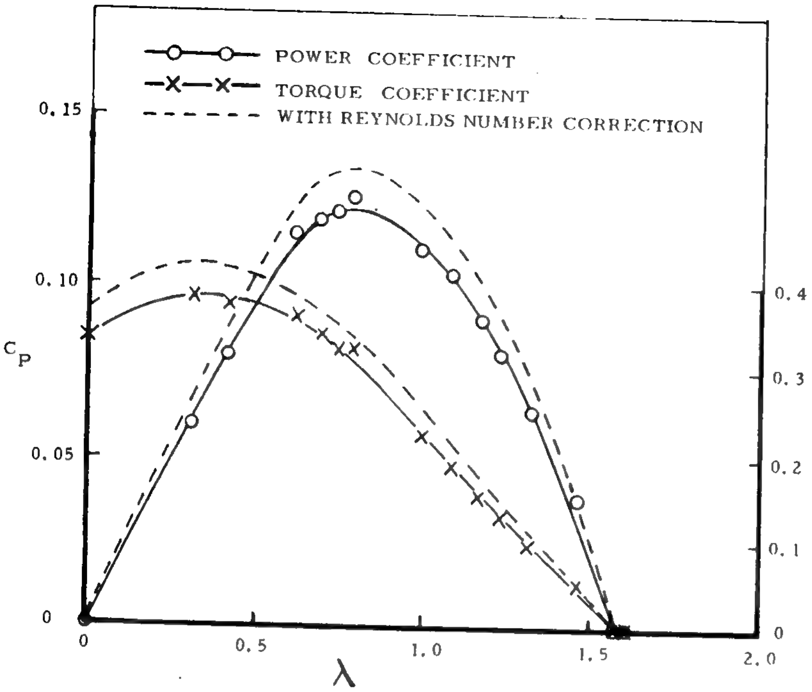

FIG. 3 EXPERIMENTALLY OBTAINED PERFORMANCE OF A MODEL 24-BLADED PERIMETER-BLADED ROTOR. DOTTED CURVES REPRESENT EXPECTED FULL-SCALE RESULTS

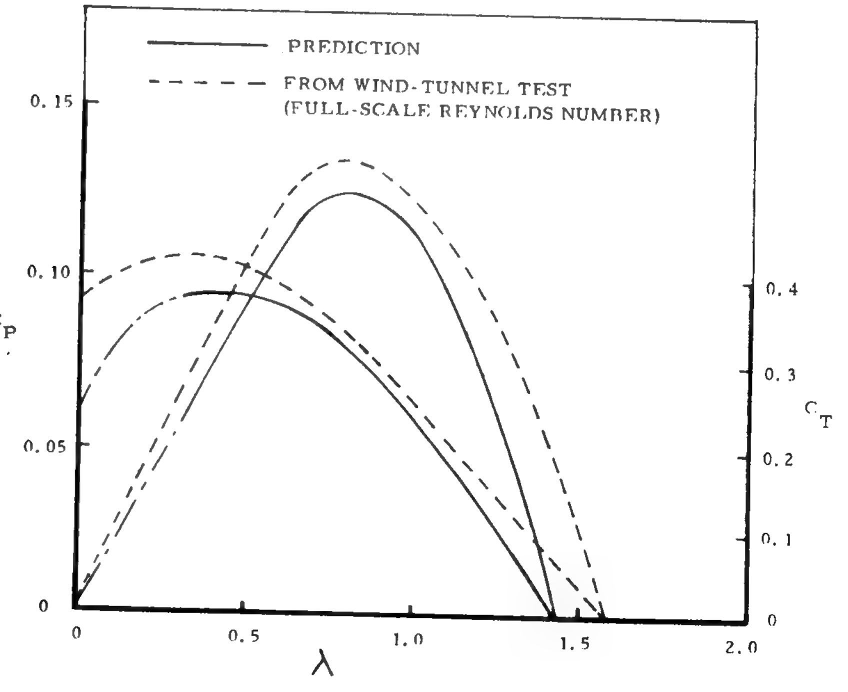

FIG. 4 COMPARISON OF PREDICTED PERFORMANCE WITH EXPECTED FULL-SCALE EXPERIMENTALLY BASED RESULT OF FIG. 3

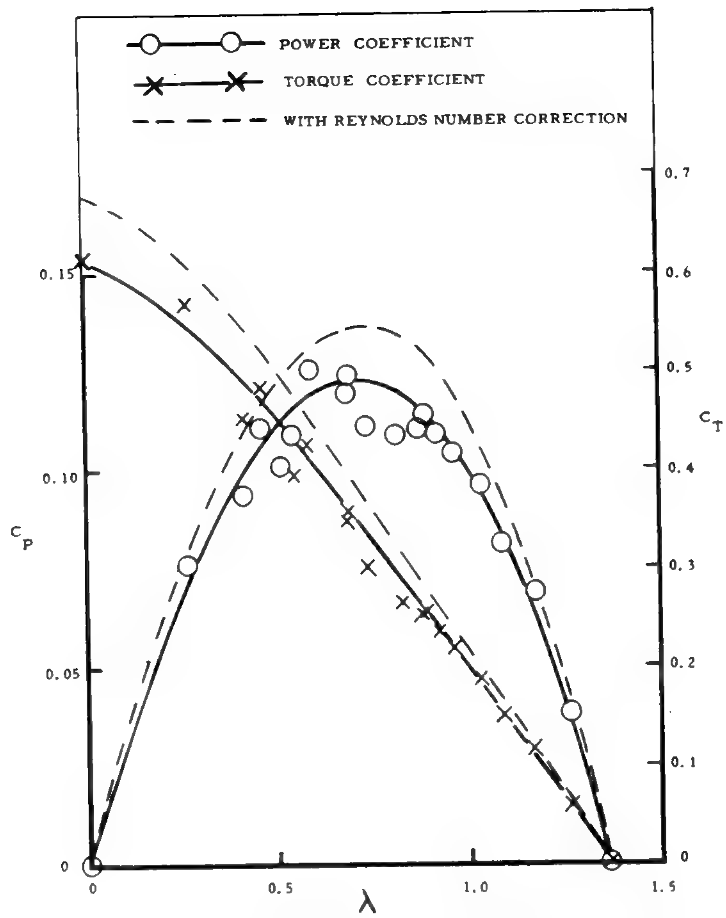

FIG. 5 EXPERIMENTALLY OBTAINED PERFORMANCE OF A MODEL 32-BLADED, VORTEX-FLAP EQUIPPED, PERIMETER-BLADED ROTOR. EXPECTED FULL-SCALE RESULTS FOR 4.9m DIAMETER ROTOR SHOWN DOTTED

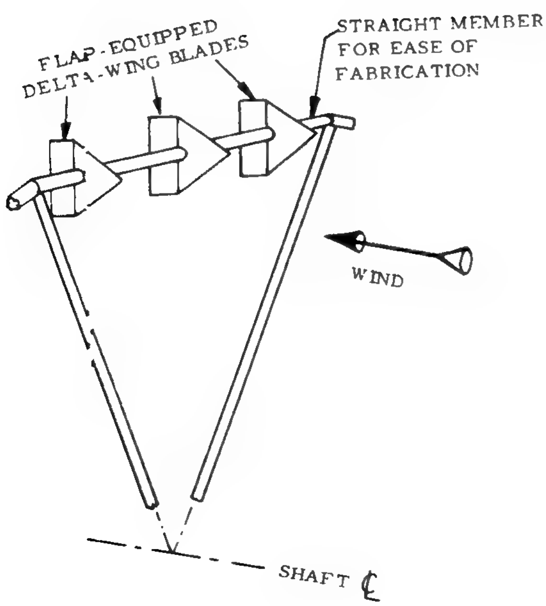

FIG. 6 PREFERRED FORM OF GEOMETRICAL ARRANGEMENT OF A PERIMETER BLADED ROTOR. EXAMPLE ILLUSTRATED HAS 8 MAIN SPOKES AND 24 BLADES

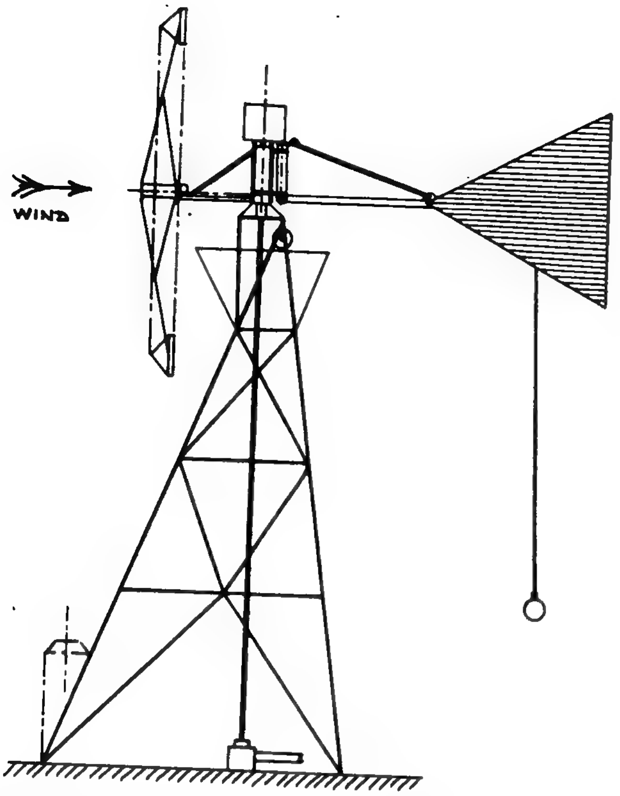

FIG. 7 VIEW, AT RIGHT-ANGLES TO WIND, OF PROTOTYPE CONFIGURATION SHOWING TOWER STRUCTURE (DIAGRAMMATIC)

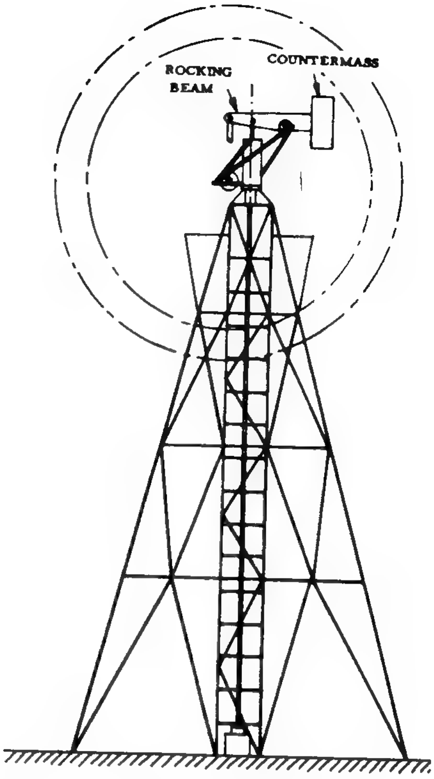

FIG. 8 VIEW, LOOKING DOWNWIND, OF PROTOTYPE CONFIGURATION (DIAGRAMMATIC)

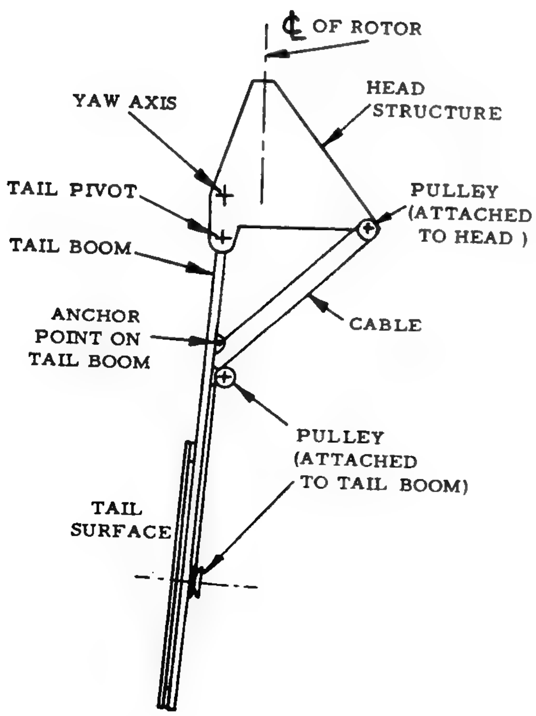

FIG. 9 PLAN VIEW SHOWING CABLE SYSTEM FOR MANUALLY FURLING THE MACHINE (DIAGRAMMATIC)

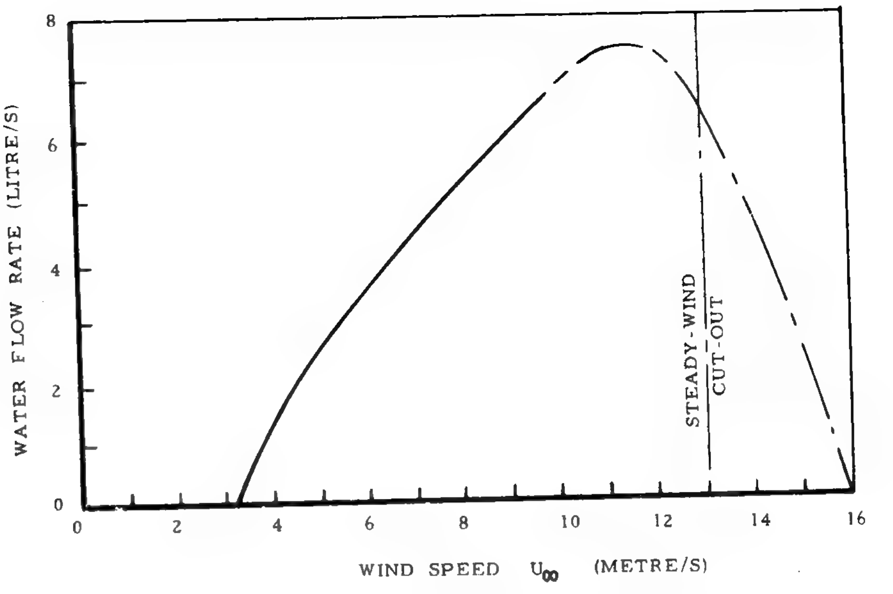

FIG. 10 PREDICTED PUMPING PERFORMANCE OF THE PROTOTYPE UNIT FOR A LIFT OF 5.5m. LETHBRIDGE, ALBERTA, TEST SITE CONDITIONS

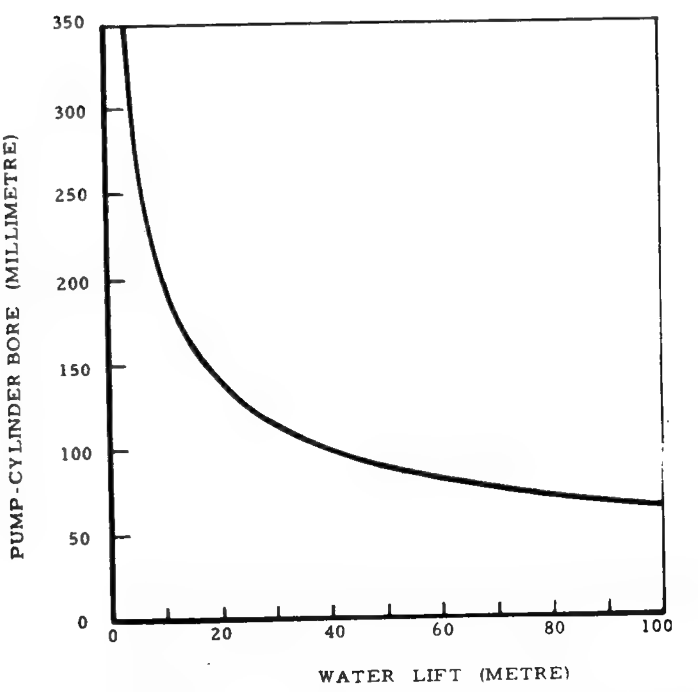

FIG. 11 WATER PUMP CYLINDER BORE VERSUS LIFT FOR 4.9m DIAMETER TURBINE; STROKE 165mm

BIOMASS - A SIGNIFICANT SOURCE OF ENERGY

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ABSTRACT

The present status of biomass as a source of energy is analysed and its future role in the energy matrix is forecasted taking into account the foreseable difficulties with the consumption of fossil fuels. Its uses for cooking purpose, ethanol production and electricity generation are discussed emphasizing the present low efficiency of the energy services provided. Such low efficiency is more evident in developing countries with a negative reflex in the amount of financial and human resources required for its use. Using agricultural yields from Brazil, an evaluation of the total amount of energy required for global consumption is made assuming that high technology, presently available, is used worldwide. Electricity produced by advanced gas turbines and ethanol from well managed crops are examples of the state of the art of such high technologies.

1 - INTRODUCTION

Today biomass is responsible for the production of 55 EJ of energy (14% of the energy consumed worldwide) . The biomass contribution is even more significant when we consider only the developing countries - it represents 48 EJ in a total consumption of 137 EJ [1].

Intensive use of biomass in developing countries had been understood up to very recently as a sign of underdevelopment since in all developed countries biomass (mostly wood) has been replaced by other sources of energy [2]. Even in developing countries like Brazil, the evolution of the profile of primary energy sources versus time has shown a decline of biomass's importance up to 1978 when the historical tendency has changed (see Figure 1), as a consequence of the National Alcohol Program (PNA).

Preference for different energy sources at different time is justified by many factors and its availability is

probably the most important one. In some circunstances replacement of one source of energy by another has occurred before the exaustion of the older one. This is an important consideration since there are many discussions about the lifetime of existing oil sources. Some pessimists had foreseen the vanishing of oil reserves by the end of this century and today they are intensively criticized since new and large oil discoveries (and reevaluation of known reserves) had been added to the existing World reserve, extending oil availability for at least the first decade of the new century. This has ocurred as a consequence of higher oil prices and consequent decrease in World oil consumption. This fact has supported the optimistic argument that as price become higher more oil will be found.

Neverthless, at present, there is a general agreement that sooner or latter oil reserve will be exausted and the only disagreement is if it will last for another 2 or 4 more decades.

It is also well accepted that other sources of fossil fuels are available and that natural gas probably will be the leading fraction of energy consumption by the year 2000 [2]. Even so its global amount is probably lower than oil and, as the developing countries demand more energy n the coming years, natural gas should be the leading solution for only one or two decades. Coal reserves are much more significant and they should be able to support World energy needs for a century or more [3]. The concern with the short lifetime of natural gas reserves is visible in United States through legislation (FUA - The Powerplant and Industrial Fuels Use Act) which allows the use of natural gas for electricity generation in new plants only if another energy alternative is identified as economically viable to run the facility when required. Coal, once gasified, has been choosen as an alternative [4].

Returning to the question of the displacement of one fuel by another before its exaustion, we should take into account that there are major concerns with the envirorment, which could justify the replacement of fossil fuels much in advance of their anticipated lifetime. Acid rain is a major problem at the proximity of the energy plant and so has a direct effect over populations that uses the energy. The Greenhouse Effect is another problem, since it disturbs the World climate and as such has also direct effect over the population that do not make profity of the energy produced.

Taking into consideration the problems caused by the finite quantity of fossil fuels (mostly in liquid and gas form) and the severe damage to the environment caused by their uses, it is understandable the growing interest for the use of biomass as an energy source, since it is renewable and not agressive to the climate if properly handled.

2 - EFFICIENT USE OF BIOMASS

Solid fuels are much more difficult to use and therefore less useful than liquid or gas. The most extensive use of biomass in developing countries is for cooking - a very inefficient way of using energy since most stoves (open fire or confined fire) have very low energy efficiency. Figure 2 shows energy expenditures for cooking, on a "per capita" basis in some countries, measured in tonnes of wood or tonnes of wood equivalent per year, when biomass or other fuel are, respectively, used.

The figures are impressive, when we notice that in some cases they are as high as one tonne of wood, which means an energy value of 0.6 kW.year/year (or just 0.6 kW) - an amount of energy very near the 1 kW value of energy necessary to fulfill human basic needs, if the already available technology for energy efficient use was widely used [5]. The use of conventional natural gas stoves (not an optimized one which is already available [6]) could reduce the energy required to less than 0.1 tonnes of wood equivalent (as displayed in Figure 2). This sort of information shows that, as more underdeveloped the country is more primary energy is being used to fulfill an energy service,such as cooking, with the negative consequences that more money or labor must be invested.

Another significant example can be observed in the alcohol industry in Brazil,or in few other countries, which decided to use this product as an alternative fuel to gasoline.As shown in Figure 3, the amount of electricity presently produced at the sugar mills is in average 20kWh per tonne of sugar cane harvested, when it is technically possible to produce more than 100kWh with the same kind of equipment (steam turbines).In Brazil the average is even lower, near 14kWh per tonne of sugar [7]. With better equipment (gas turbines) it is possible to generate near 500kWh per tonne of sugarcane harvested, as can be seen from the same Figure.

This technology is emerging as quite promising for high efficiency biomass utilization. Gas turbines have been improved in the last years as a consequence of the large investments in research and development for the military aircraft industry. So, while steam turbines have reached its maximum efficiency in 1965 (busbar electricity/heat value of fuel = 32%) and since then stagnate, gas turbines efficiences are continously being improved, reaching 47% today [8] and more than 50% at the begin of 1990 [9].

High efficiency is explained by the use of high temperature turbine inlet air (1200 C), steam injection in the combustion chamber (steam produced from the energy available in hot gas at the turbine exit), intercooler as a way of reducing mechanical energy requirement for the air compressor, and the possibility of using high efficient wood gasifier. All these technologies are proved at a commercial or an experimental level, except the intercooler whith was

evaluated only theoretically [10]. The most critical steps for the sucess of this technique are wood gasification and construction of the intercooler - both steps deserve efforts for optimization.

Biomass gaseification and the operation of a turbine with producer gas has been performed by the aeronautical turbine division of General Electric (GE), as a side effort in the project to operate gas turbines with producer gas from coal. GE used a Lurgi gasifier, developed in Germany during the Second World War, which operates under pressure. Results were quite interesting since it was possible to operate the turbine without the cumbersomes equipments required for SO2 remotion. Removal of SO2 at low temperature is a well known technology, used in the successful Coal Water Project [11]; but in order to reduce costs and improve efficiency it is important to avoid the gas cooling stage and to develop a hot gas SO2 removal equipment. GE has concluded that it is more feasible to run a turbine with hot producer gas derived from wood (so without SO2) than from coal, as can be seen in the proposed time schedule for development shown in Figure 4. This schedule guarantees the operation of a commercial 20 MW turbine based in wood gaseification earlier than coal based turbines.

To reach the 500kWh/tonne figure will require not only the operation of an energy efficient gas turbine, but also a new way of harvesting sugarcane. Nowdays harvesting is preceded by firing sugarcane leaves and succeeded by cutting of tops and trash which are left on the field. Firing is undersirable since the amount of air polution caused by particulates disturbs rural population; also the risks of uncontrolled fire and of damage to the electric network are considerable. So, probably, the new harvesting process will be a "must" other than a new approach. Under this framework much more biomass will be collected. In Brazil, were 230 million tonnes of sugarcane are annually harvested, 55 million tonnes of dry biomass could be produced if only the minimum amount of trash, required to avoid soil deterioration, were left on the field. Such quantity of bagasse and sugarcane residues (barbojo) adds up to 1.15 EJ - equivalent to 211 million barrels of oil per year or enough to produce 160 TWh of electricity (with 47% efficiency), which are, respectively, 53% and 80% of the country total energy use [12].

3 - ENERGY YIELD FROM BIOMASS

Another important figure to consider is the yield of energy derived from biomass per amount of land used for crops or forests. In the case of Brazilian sugarcane, which uses 4 million ha of crop area we can get a yield of 40MWh of electricity per hectare which translates in 4.65 kW/ha of firm power. It is useful to quote the average value of firm hidroelectric power that is produced in the southeast and the central area of Brazil per hectare of flooded area, which is 10kW/ha. One should add that the more conveniently located dams have been built. With the new ones to be

erected, at less favourable geographical areas, there will be a tendency for a decrease in the amount of kW per ha. On the other side an improvement of technology should rise the figure quoted above (4.65 kW/ha). This figure is significant if we remember that in addition to the electricity produced, sugarcane crop will deliver an average of 4,600 l/ha-year (or in well managed Brazilian plantation up to 7,000l/ha-year [13]), which is enough fuel to power, in Brazil, 4 automobiles per year. So, 1 ha of sugarcane crop, with the use of sugarcane residues is enough to supply the energy requirements of almost 5 persons, including the energy required for personal transportation.

The high yields quoted above can also be reached with wood derived from man-made forest. Well managed eucalyptus plantation in tropical countries yields 15 tonnes/ha-year [14], which is enough energy to produce 70 MWh/year of electricity, equivalent to 8 kW of firm power.

4 - CONCLUSION

The above exampíes highlight the important paper of new technologies to convert biomass in liquid or gaseous fuel. These technologies are of central interest for developing countries, the ones which presently use large amounts of biomass with low efficiency; but as the local and global concern with the environment emerge, developed nations will also be interested in the problem. The total amount of biomass used as energy in the World - 55 EJ - corresponds, if used with 100% efficiency, 0.29 kW of energy per capita or 29% of the energy required to fulfill basic human needs (1 kW according ref. [5]).

It is clear therefore that if we could triplicate the amount of biomass used today, the majority of the energy requirements ,in the scenario already discussed, could be provided from biomass with the use of energy efficient convertion technologies . Such target is not far from reality since:1) large biomass resources are available in natural forests which can be exploited in a continuous form (see Fig.5) ; 2) large amounts of biomass are not presently directed to the energy market (as is the case of sugarcane residues); 3) present biomass energy yields which are already high when compared with other sources of energy (as hidroelectricity) can be easily improved, as was shown by the impressive gains in crop productivity promoted by the Green Revolution. In tropical areas we have shown that as much as 5 to 8 kW/ ha can be produced yearly - so at a consumption level of 1 kW per capita, present global energy could be obtained from the exploitation of 1200 to 750 millions hectares of land, that is 12 to 7,5 times the amount of cultivated land in Brazil, a country were only 10% of its area is used for crop production.A previous study for Latin America showed that 0.56 ha per inhabitant should be able to provide all the energy required in the region (using less efficient convertion technologies as compared with the present paper) and that 4 ha of natural forest woodland on a per capita basis is available [15].

With the present yields biomass could be the largest energy source for the World, provided well known energy efficient conversion technologies are used.

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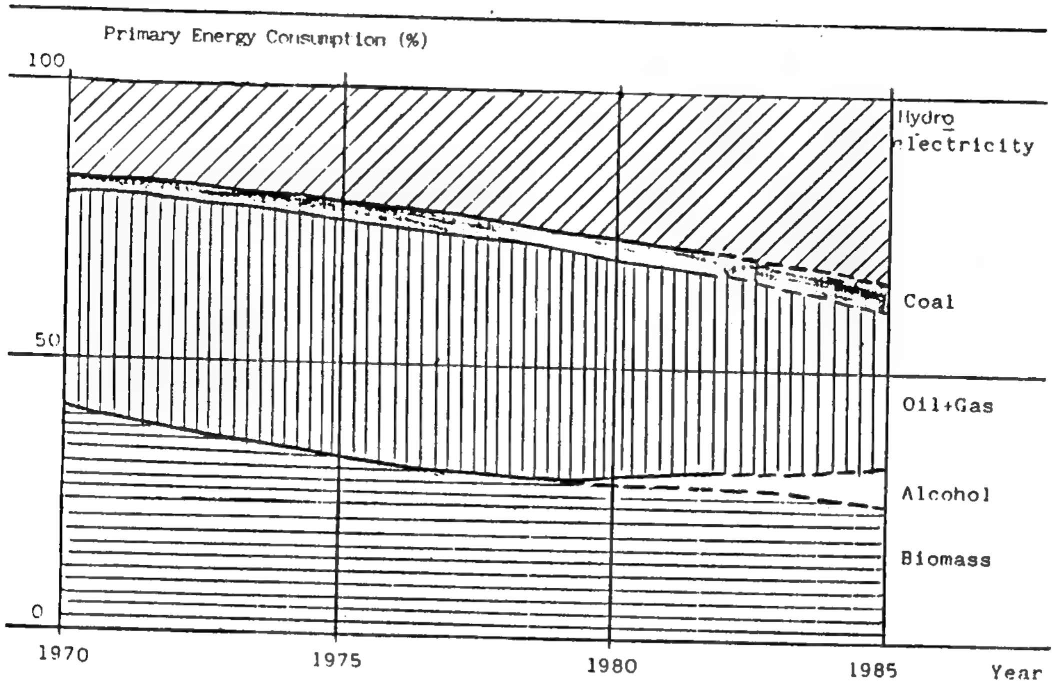


FIGURE 1. Primary energy profile in Brazil (%)

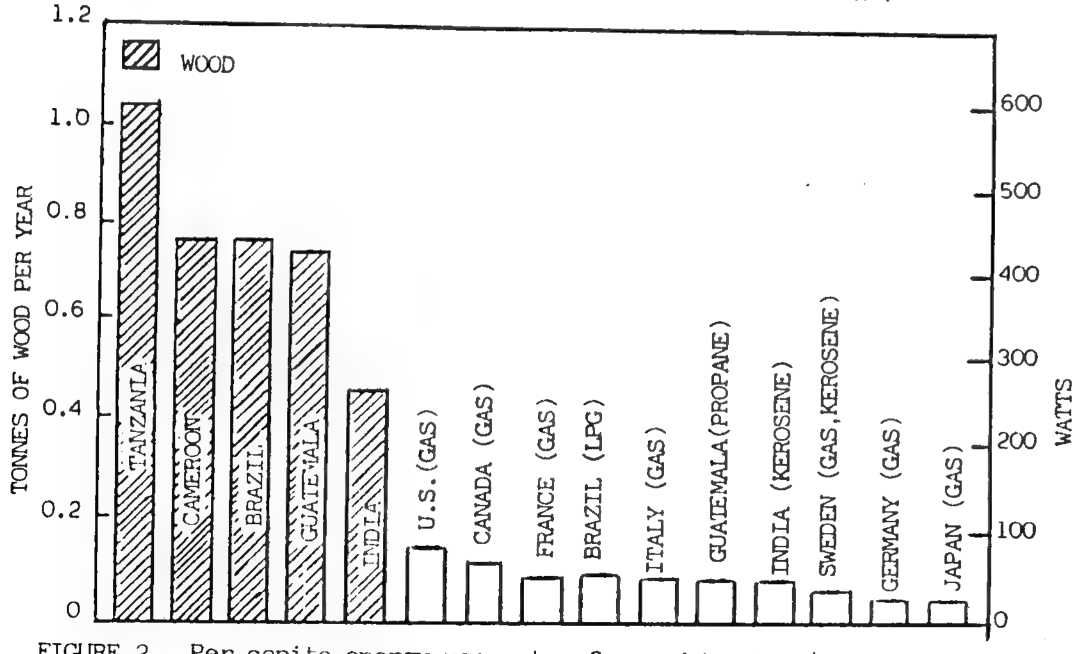
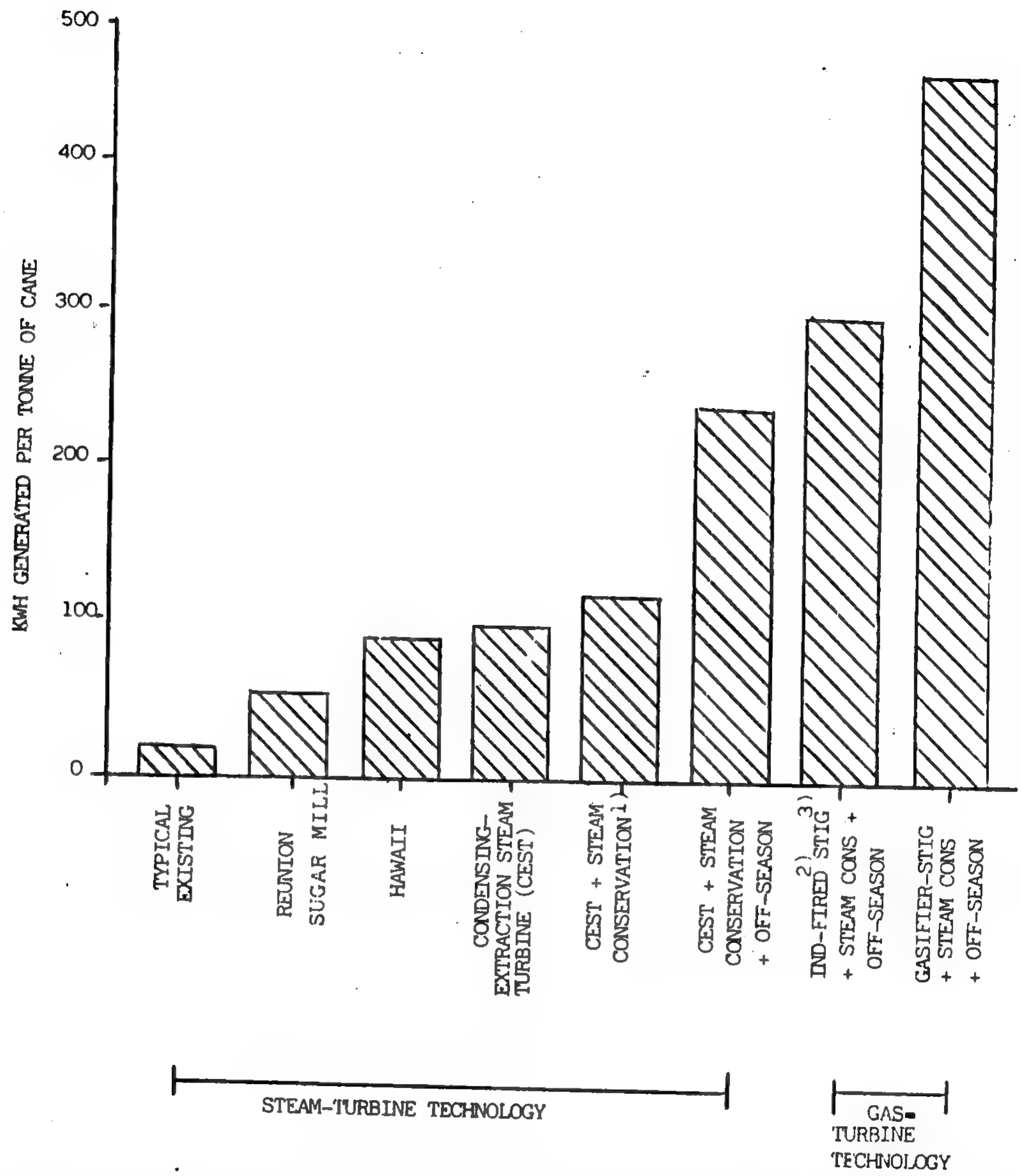


FIGURE 2 - Per capita energy-use rates for cooking.For both wood stoves and stoves involving high-quality energy carriers, the per capita energy-use rate for cooking is expressed in Watts. The wood consumption rate is also given in tonnes of dry wood per year.[5]



1) Process steam used at the factory can be reduced from over 400 kg/tonne of sugarcane to 300 kg/tonne with present technology.
2) Ind-Fired requires the use of a conventional bagasse boiler to heat up compressed air discharged at the turbine.
3) STIG- steam injected gas turbine.

FIGURE 3. Electricity generating potencial from sugar cane residues at a raw-sugar factory per tonne of cane crusched. [10].

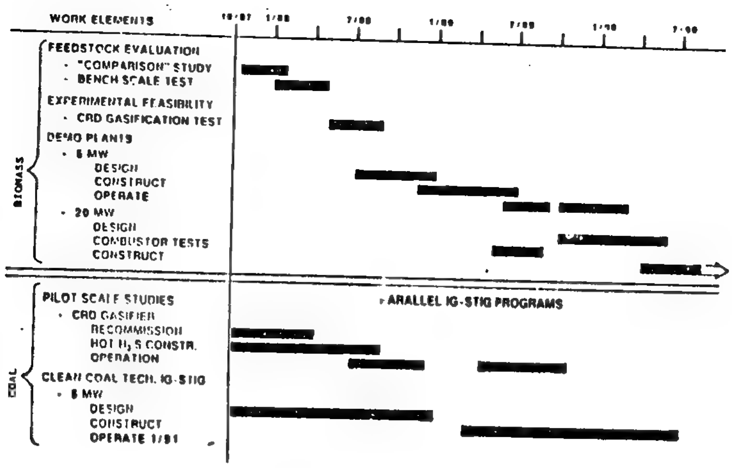
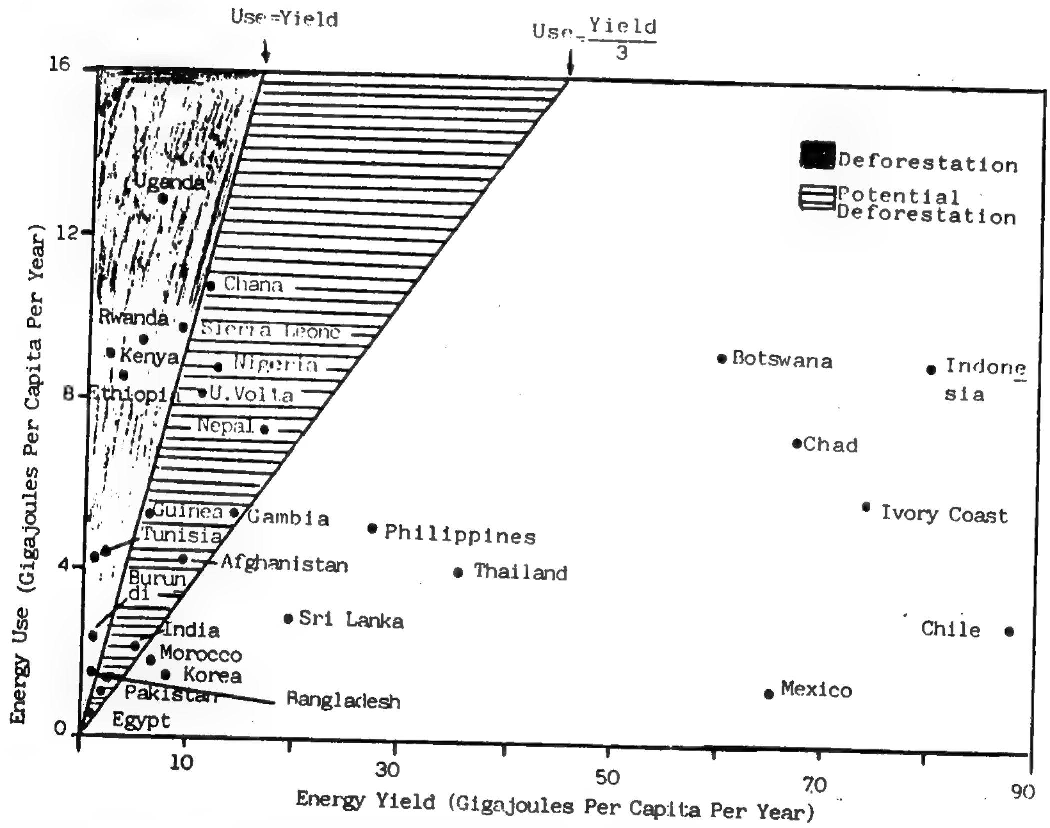


FIGURE 4. Preliminary Program Schedule proposed by General Electric for the development of biomass and coal gas turbines coupled with gasifier.[16].



Countries With Higher Yield Than Shown on the Figure

Country	Gigajoules Per Capita Per Year
Congo	570
Brazil	340
Angola	334
Zaire	323
Cameroon	240
Sudan	220
Malaysia	160
Argentina	120
Burma	110

FIGURE 5. Fuelwood use rate versus fuelwood production rate in some developing countries.
Source : Ref. [17].

SECTION XV

WIND ENERGY DEVELOPMENT

WIND RESOURCES AND EXPLOITATION IN SOMALIA

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Abstract

A program for the study and the exploitation of the wind energy is presented. First objective was the improvement of the knowledge of the wind distribution and characteristics. A network of 11 new, well placed, periodically checked anemometric stations has been realized; local data are computerized and analyzed by statistical methods. A new theoretical approach (irregularity analysis) has been pointed out in order to characterize the energy distribution according to the kind of energy exploitation and storage. Territorial wind intensity and energy maps have been realized. At the same time, a program for testing conventional multibladed water-pumping wind-mills has been carried out in order to verify the reliability of these machines, together with the design, construction and testing of a wind electric pumping system. Informations are given on some feasibility studies.

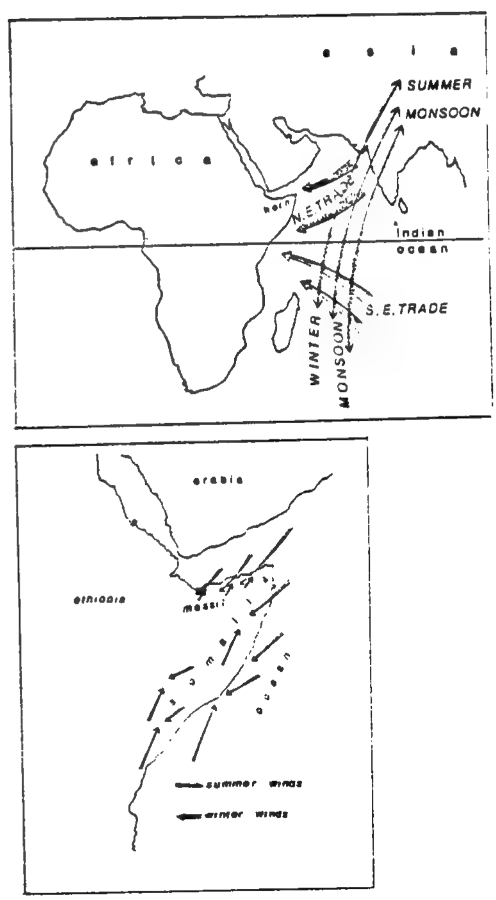


FIG.1: Configuration of the winds in the Horn of Africa

1. Introduction

Owing to its placing in a trade-monsoon climatic area, Somalia is a favourite country as to wind energy. Winds are intense and regular, particularly in the north and along the coast band. The winds become weaker inland, but the energy distribution is suitable for exploitation in most part of the territory. **Fig.1** shows the wind configuration of the area.

Further characteristics that thrust to work out an eolic plan are:

-Somalia is a semiarid country, three-quarters of which are flat land;

-the country is rich of livestock and of underground waters, but is poor in rain and surface waters; therefore feeding is scarce;

-most people (about 6 millions) live in little villages or are unsettled; water and energy needs for people and for livestock are intense but are scattered through the country.

It is a country most water and energy needs of which could find solution by means of the fulfilment of a project including the installation of a lot of little-medium water-pumping wind-mills and aerogenerators, partly built in the country, and the training of engineers. Although such a complete project was not born yet, the Somali National University (SNU) has being carried out a program of research that is addressed to the objective of the exploitation of the wind resources of the country, with four fields of activity: a) wind analysis and maps; b) installation and testing of two commercial multibladed water-pumping wind-mills; c) design, building and installation of a Wind Electric Pumping System (WEPS); d) feasibilities of water/energy wind-plants in areas and villages of interest. In Refs. [1],[2],[3],[4],[5] the details of this activity can be found.

2. Wind analysis and Maps

As the metheo national stations are too few and their data are often unreliable, eleven new anemometric stations were set up in southern Somalia (one electric self-generating anemograph, three wind-cup monthly mechanical anemographes, seven wind-cup counter anemometers). Four stations more are going to be set up. Fig.2 shows the dislocation of the State stations and of the S.N.U. stations. All the data are stored in computer. The data provided by the anemographes are continous and are stored as hourly data; the data provided by the counter anemometers are hand recorded by local responsibles 5 or 3 times during the day and are stored in that form.

Computer codes have been realized to carry out the statistical analysis of the data. The local **mean wind speed** V_m and the local **cubic mean wind speed** V_{m3} (proportional to the available wind

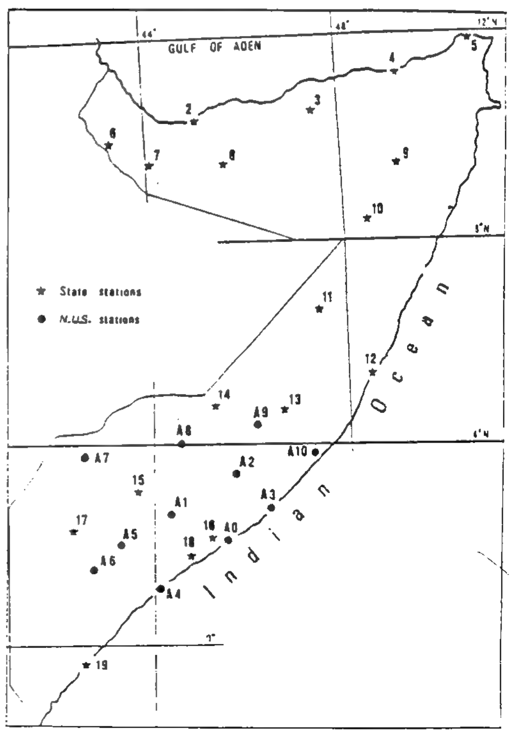


FIG.2: Location of the State and of the SNU stations

energy), by the help of some criteria of space and time extrapolations that are allowed by the orographic nature of the country, let us to draw up the maps which are showed in **Fig.3** . Although these maps are just a first approximation (some years of data more are needed for a correct analysis), it can already be seen that a larger part of the territory is interested by mean wind speeds higher than 5 m/s.

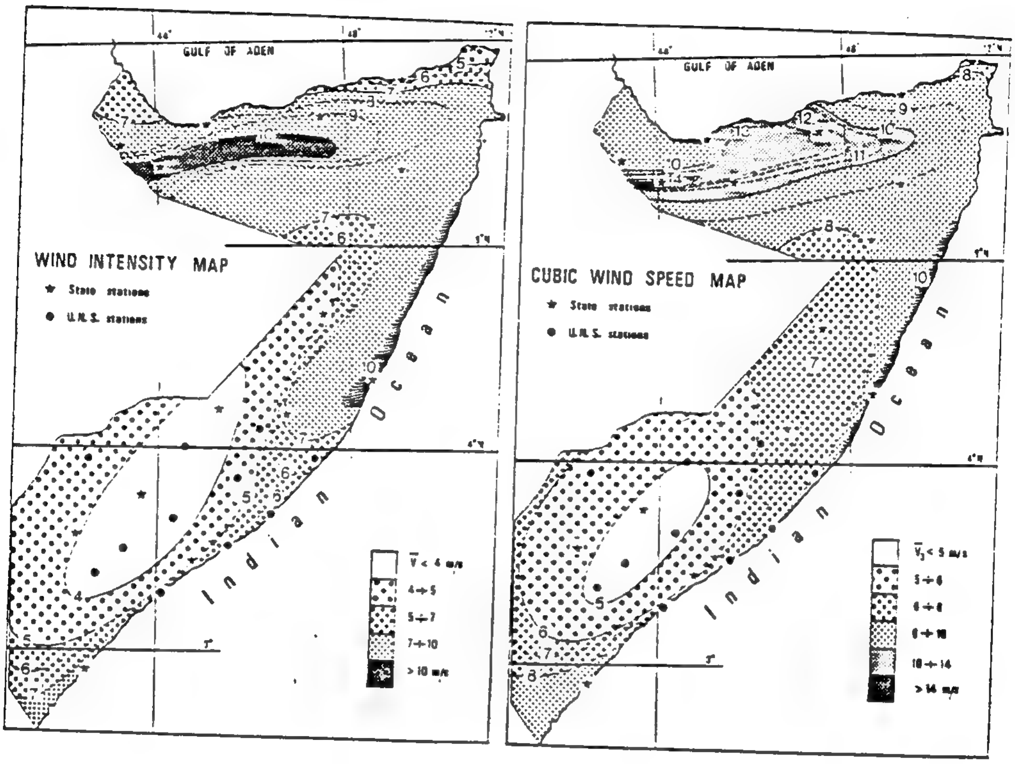


FIG.3: Wind intensity map (mean **wind speed**, m/s) and **wind energy** map (**cubic mean wind speed, m/s). Winds at 10m of elevation**

A method of analysis according to wind irregularity has been developed classifying four levels of wind fluctuations, depending on the time scale: 1)**gusts** (short-scale fluctuations shorter than 10'), 2) **storms** (duration between 10' and 1 hr), 3) **breezes** (duration between 1 hr and 1 day) and 4)**trade-monsoons** (seasonal variation longer than 1 day). The short, medium and long scale wind irregularities are measured by three **wind-coefficients of fluctuation** defined as the ratio between the cubic mean wind speed averaged over two subsequent levels of irregularity. The product of the three is the **wind-continuity coefficient**:

$$k_c = V_{m3}/V_m \qquad (1)$$

that is the measure of the overall effect of the wind irregularities of any scale. Its product by V_m gives the cubic mean wind speed V_{m3}. When the cumulative value of the wind-coefficients of fluctuation and of the wind-continuity coefficient is calculated, an asymptotic trend is found which shows that after a period of time (the length of which depends on the place, but is never longer than one-two years) a stable value of the coefficient is achieved. **Fig.4** shows the time-trend of the three coefficients of fluctuation (k_m: storms; k_h:breezes; k_d:trade-monsoons) in two somalian localities.
This behavior means that the energy estimate needs the measurement of the instantaneous wind velocity (by means of anemographes) during few months

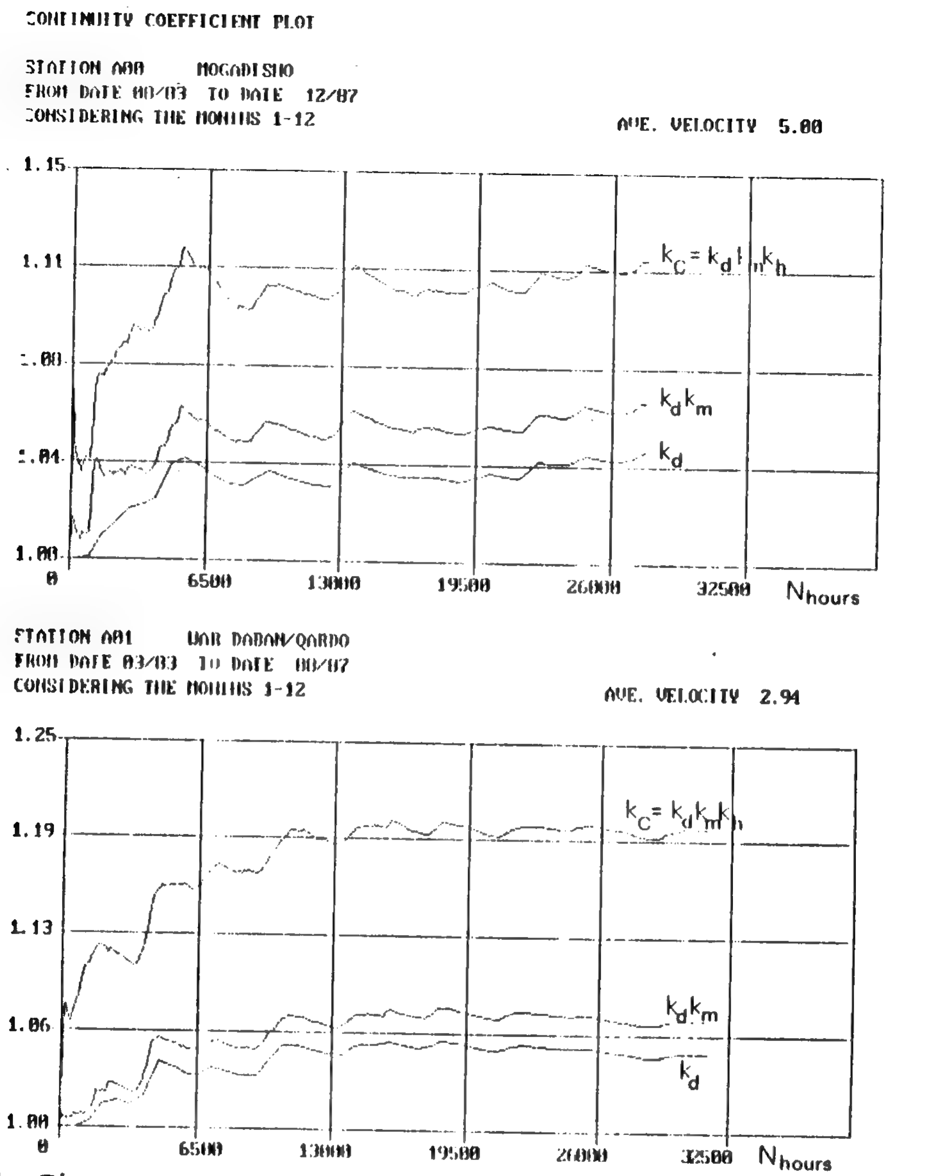


FIG.4: Time-trend of the three wind-coefficients of fluctuation in Mogadisho (coast) and Qardo (inland)

only, together with the measurement of the mean wind speed (by means of counter anemometers, the reading of which can be made from time to time) during many years. This idea allows the knowledge of the energy distribution of a given territory by using a restricted number of sophisticated and costly instruments together with a large number of simple, cheap, not-guarded instruments. This idea is going to be applied in the somalian wind program.

Besides, a cumulative coefficient of the machine behaviour has been defined: as a quadratic low for the actual shaft power P_s in the rising range (between cut-in speed V_i and rated speed V_r) can be assumed, that is:

$$P_s = a\,V^2 - b \tag{2}$$

the energy that will be supplied in the period T will be:

$$E = T(a\,V_{m2}^{\;2} - b) \tag{3}$$

where V_{m2} is the **quadratic mean wind speed** in the rising range. The shaft-

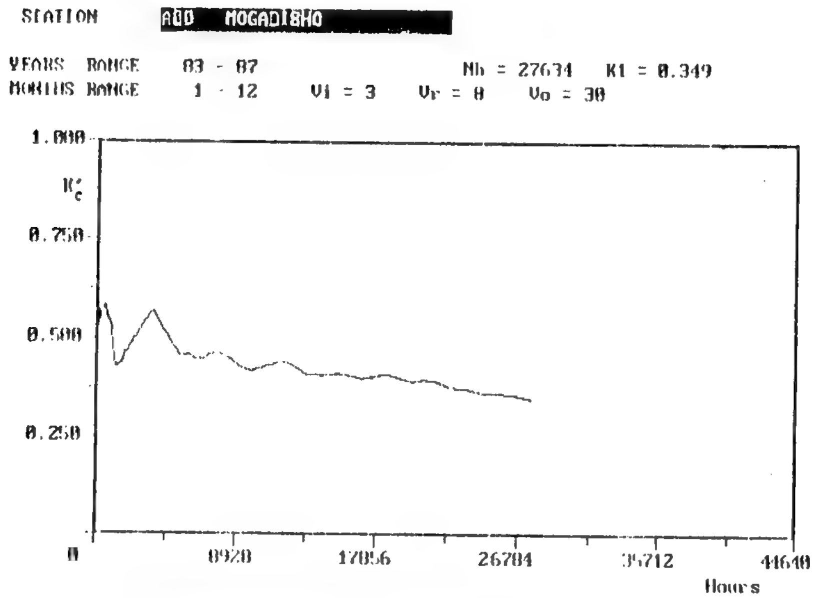
coefficient of continuity is defined as:

$$k'_c = f_1(V_{m2}^{\ 2} - V_i^{\ 2})/(V_r^{\ 2} - V_i^{\ 2}) + f_2 \tag{4}$$

where f_1 and f_2 are the wind frequencies in the ranges $V_i<V<V_r$ and $V_r<V<V_c$ (V_o = cut-out speed). Then the total energy is given by:

$$E = T\, P_r\, k'_c \tag{5}$$

where P_r is the rated power. **Fig.5** shows the time-trend of the shaft-coefficient of continuity for the same localities of Fig.4.



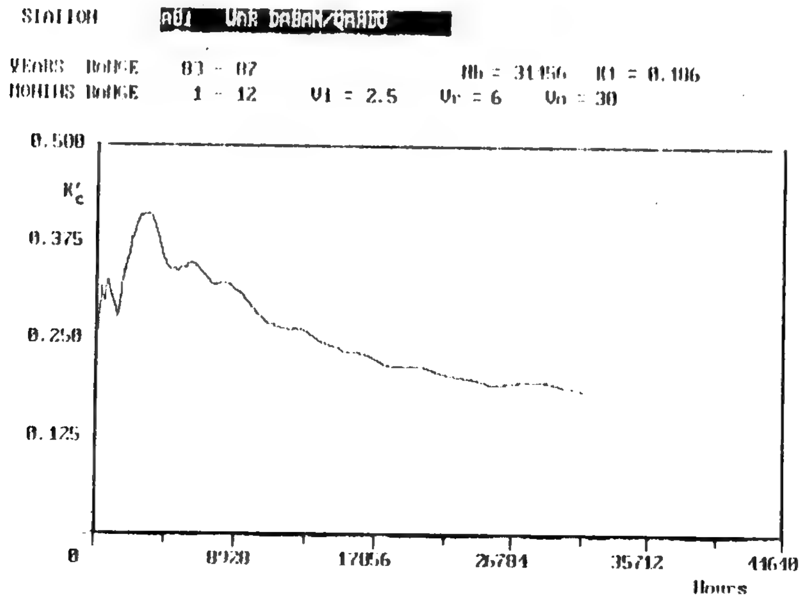


FIG.5: Time-trend of the shaft-coefficients of continuity in the localities of Fig.4

3. Water-Pumping Wind-Mills

Two conventional multibladed-reciprocating pump wind-mills, 5-meters rotor, on a 15-meters tower, have been set up and tested in two very different sites. In Mogadisho the wind-mill works on a borehole-well with the pump 86 meters down, at yearly mean wind speed little more than 5 m/s; in Adale (a little village on the coast) the wind-mill works at yearly mean wind speed of 8 m/s on a large 6 meters deep dug-well. Test were carried out by measuring wind speed, water delivery and strokes per minute. **Fig.6** shows the results anc a good agreement with a theoretical model.

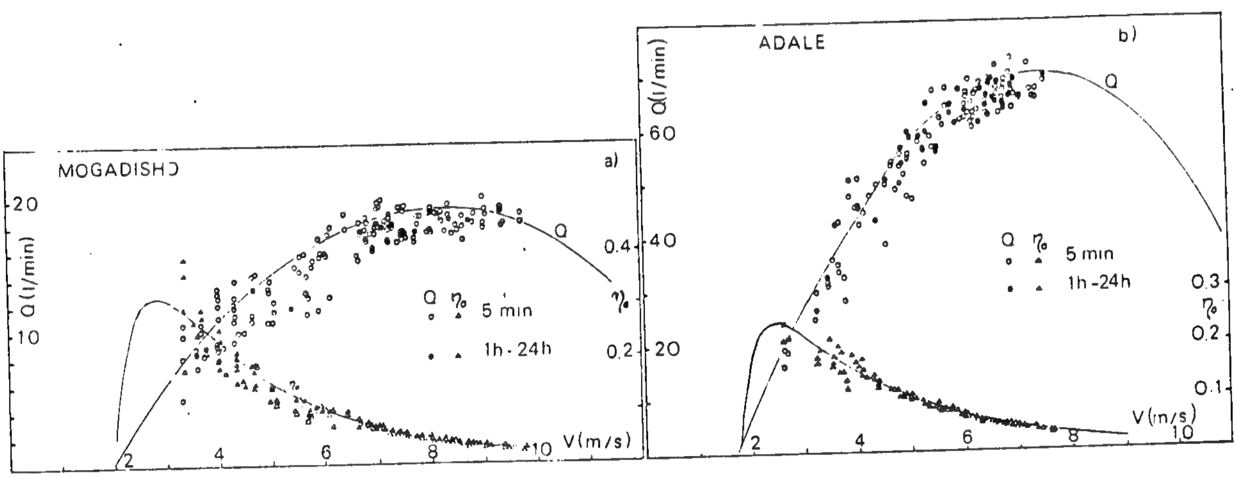


FIG.6: Results of the tests of the multibladed water-pumping wind-mills

However, none of the two machine gave good results form an operative point of view. Both encountered many troubles, failures and damages for several reasons, the main of which are: the Mogadisho aquifer is too deep (therefore, the rod is too long) for the mechanical resistance of this machine, while the Adale winc-speed is too high for a multibladed wind-mill; the underground waters are rather salty, and intense electrocorrosive activity took place between metals (steel and bronze); mechanical vibrations, sliding down of the well, marine corrosion of the air-exposed components were some other troubles. The authors' experience and the common observation of the many multibladed wind-mills existing in Somalia suggest that these troubles are very frequent and that this machine has many probabilities to go out of order in few months when a continous and accurate maintenance cannot be assured.

Some of these drawbacks can be avoided with more careful and costly design of the machine components, but we lean to conclude that multibladed water-pumping wind-mills are reliable machines provided used for moderate winds and moderate water heads and provided continous maintenance is assured, which is not always available in remote localities and not-guarded plants.

4. Wind Electric Pumping System

In most somalian places a fast, fixed-blades aerogenerator coupled with a submersible centrifugal pump is from many point of view preferable to multibladed wind-mills: fully rotational motion is more reliable than rotational/reciprocative one; centrifugal pumps are suitable for constant efficiency coupling with wind turbines in a wide operative range; electric power allows easy alternative connection when wind is not available; medium-solidity, fixed-blade turbines are more suitable for good intensity, regular winds than both multibladed and variable pitch turbines; submersible centrifugal pumps are available for sale and replacing anywhere; aerogenerators can be sited independently and apart from the well, which is essential when replacing existing pumping systems.

On the grounds of these considerations and of the will to develop an appropriate technology by choosing technical solutions that could be not only installed but also realized in a developing country, we built a WEPS (Wind Electric Pumping System), expressly designed for the somalian climatic conditions. In [5] a detailed description of the machine and of the tests can be found; but some informations are given here.

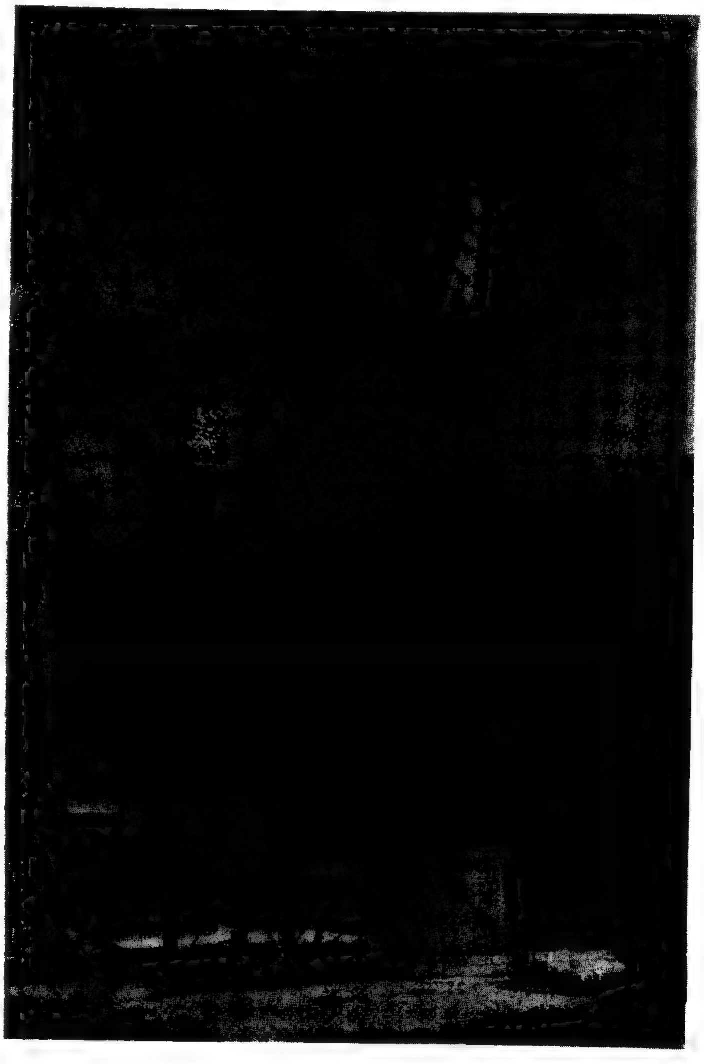


FIG.7: The WEPS in the test field

Fig.7 shows a view of the WEPS in the test field. The rotor is a two-blade, made by curved steel plates. The aerodynamics of this rotor has been studied by CWD [6], and we assumed their data for the design, as we have no means to test rotors; tests showed excellent agreement with this calculation. The design wind speed is 5 m/s, but the coupling with centrifugal pumps in the optimum efficiency range allows the machine to get a good efficiency in a wide range of wind speeds (in this case: from 3 up to 15 m/s), being this a main merit of a well designed WEPS compared to multibladed WPWM. The pump head is 20 m; the total speed ratio between pump and rotor is 18, obtained by a 1.5 cog-belt ratio and a 12 electric ratio (between a 12-poles alternator and an unipolar motor). The generator is a 12 pole permanent magnet alternator; this kind of electric machine has been chosen because it doesn't need external excitation and doesn't introduce additional drag during starting.

The problem of the starting of the system -that means the activation of the water flow rate in the hydraulic plant- that takes place at too high wind speed because of both the low rotor starting moment and the high water head, is resolved by resorting to a booster multistage pump which is disconnected at higher speed. Special care has been devoted to the choice of the better coupling between rotor and pump, with the purpose that the pump maximum-efficiency load runs through the maximum-efficiency points of the rotor/wind power characteristics. The machine has been built and tested in Italy, before its setting up in an experimental area of the Somali National University , in Mogadisho.

5. Feasibility of wind plants

Althoagh no program of wind energy exploitation is going to be realized with the scientific advice of the S.N.U. at present, we studied the feasibility of some standard wind plants that are suitable for the local environment and needs. We directed our consideration to Wind Electric Pumping Systems, as this power plant can be used both for pumping and electricity production depending on the demand, both in the same day as well; however, pumping has been considered the main need and local water resource the main datum together with wind resource.

Two different plant typologies have been studied, depending on the territorial area, i.e. on the wind intensity range: slow, multibladed rotors are suitable for inland applications, and fast, two-four blade wind turbines are needed all throughout the coastal band and the northern region. Because of the low specific power, the inland plants will be suitable for moderate water delivery only, in case with a booster-machine for lifting and a feeding-machine for delivering water. The coastal plants can catch high specific power, that can be exceeding for water needs, so that either little wheels are sufficient or an electric delivery can be accomplished too during the day. In Fig.8 some of the proposed wind-plants are showed, related to the following feasibility studies:

a) UAR plants (Fig.8.1)

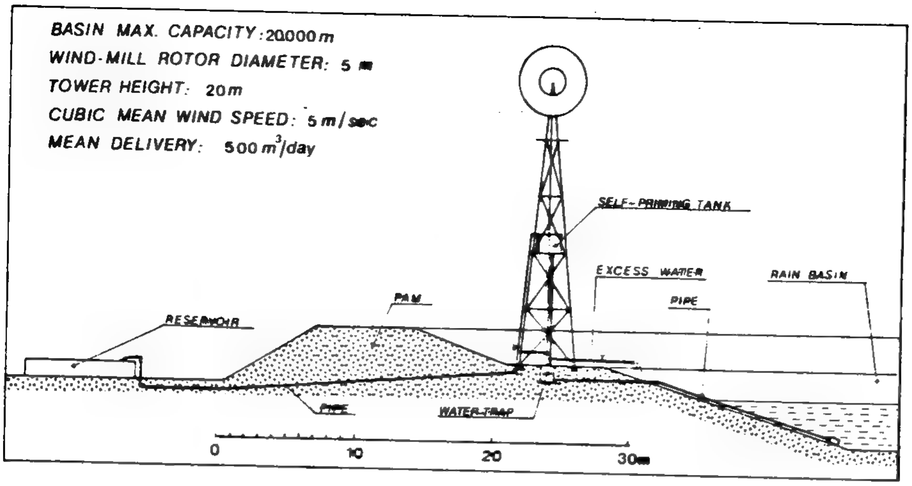
5-meters rotor, multibladed wind-mills on a 20-meters tower have been proposed to be set-up on several brush rain basins ("uar"), to sobstitute the diesel pumps and to feed the watering places by the water of the basin. 2000 heads of livestock/day can be watered at any basin (provided water is in).

b) River watering plants

5-meters rotor, multibladed WEPS on 16-meters towers by the side of the Shebelle river (and 7-meters rotors along the Juba river) have been studied to water 3000 heads of livestock/day and 1000 people/day each. Water will be delivered into a large sedimentation reservoir from which it can separately feed the livestock watering places and the people water-taps (through depurator).

c) River aqueducts (Fig.8.2)

Two aqueducts have been studied for the Shebelle river and the Juba river. Each of them needs two 5 or 7-meters rotor multibladed WEPS: one to be set up by the side of the river and to feed a large sedimentation/depuration reservoir; the second to deliver water into the pipe (about 3 km long for Shebelle and 1.5 km long for juba). About 30.000 people/day could be watered.



8.1: Water-Pumping Wind-Mill on a rain basin

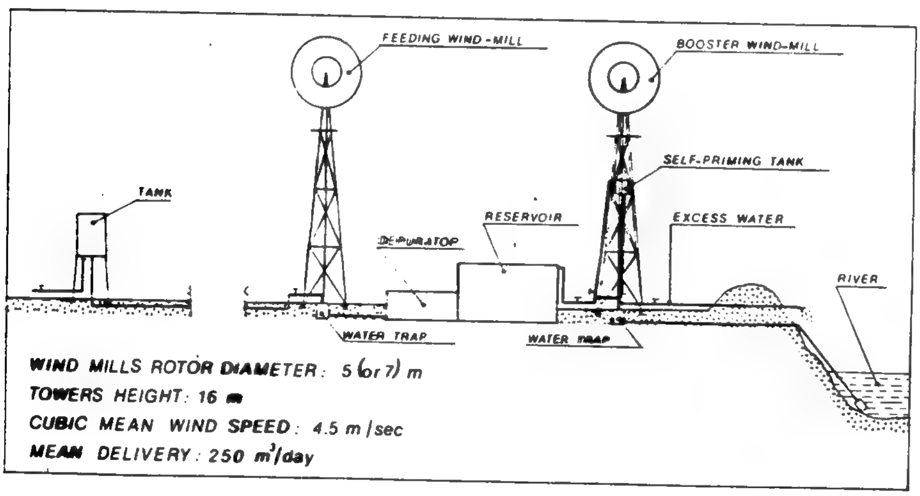
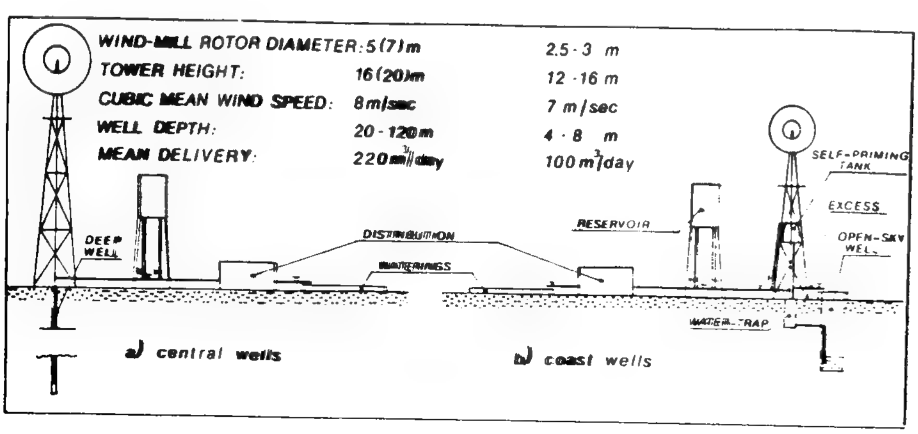


FIG.8

8.2: Wind-Mill system for river aqueduct



8.3: WEPS on wells: a)tube-wells (central Somalia)
b)dug-wells (coastal band)

d) Inland/coastal wells (Fig.8.3)

A large number of multibladed WEPS together with as many bore-wells, reservoirs and watering place systems are studied to be built in the central regions of the country, where underground waters depth is between 20 and 120 meters and cubic mean wind speed is about 8 m/s. 100.000 people and 100.000 heads of livestock could be watered per day.

All throughout the coastal band a number of 3-5 meters rotors, 2-4 blades WEPS has been studied, both for bore-wells and dug-wells, to water about 50.000 people/day and 100.000 heads/day and to provide 100 kwh/day.

e) Town wind-generators

Four little wind-farms (4-6 WEPS, 5-7m rotors, on 15m pillars) have been studied to be set up in coastal towns where the electric power needs are comprised between 30 and 200 kW, to be connected to existing electric network.

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EFFECT OF LINEARIZED BLADE SHAPES IN HORIZONTAL AXIS WIND TURBINES

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ABSTRACT

Large horizontal axis wind turbines must be designed for optimum performance and minimum maintenance. Combining The Blade Element Theory and The Axial Momentum Theory a method was developed to determine the optimum blade shapes for maximum power output from a wind turbine. According to this method the blade chord and twist angles are continuously varied at each radial elementary segments until the power coefficient corresponding to that element has been maximized. But this types of blades are difficult to fabricate and may not have the structural integrity. In order to reduce this problems, a linear distribution of chord and twist angles betwen r = 0.5 R and r = 0.9 R are suggested along the entire length of the blade. The effects of this linearization upon various performance parameters are then studied and compared with those for optimum design conditions.

NOMENCLATURE

a, a'	axial and tangential interference factors respectively
dA	differential windmill flow area
B	number of blades
C	chord of the blade
C_D, C_L	drag and lift coefficients respectively
dQ, dT	blade element torque and thrust respectively
r, R	local and total blade radii respectively
V_∞	undisturbed wind velocity
α	angle of attack
β_T	twist angle
ρ	air density
σ	solidity

ϕ angle of relative wind

Ω angular velocity of blade

1. INTRODUCTION

From ancient times, wind has been utilized as a source of power . Most familiar to us are the windmills of Holland and the rural windmills of the early 20th century. In spite of the long historical background, with the invention of steam engine, these windmills gradually went out of use day by day and served only to attract visitors. Furthermore, introduction of internal combustion engines to produce electricity, made energy available at much more convenient and economical way. Because the cost of energy produced in this manner depends almost entirely on the availability and price of fueld for running those engines.

But the trend of rapid increase of fuel price from the last decade reversed this situation once again. A revival of the interest in wind energy occured and the later is reevaluated as a potential source of energy. Though the cost of electricity produced by this wind energy system is still higher than that produced by other conventional methods, the difference is rapidly falling down. Already it is found cheaper in some parts of the World in isolated rural areas where other forms of energy are expensive.

All these fruitful achievements are the results obtained by applying the modern technological advances to the design and construction of wind turbines (as the successors of windmills are now known), which include vigourous field study and a large number of computer modelling.

2. OPTIMUM BLADE SHAPES

Besides a number of design options, the blade parameters play a vital role concerning the optimum performance of a wind turbine. The blades of a modern wind turbine must have a good aerodynamic shape resembling the wings of an aeroplane. The similarity of propeller and wind turbine enables The Propeller Theory, as developed before World War II, into theories that can be used for design, calculation and prediction of the behaviour of wind turbines [1]. Propeller Theory evolved in two different method of approach; one, which has been called The Axial Momentum Theory [2] and the other, The Blade Element Theory [3]. In the next section, the optimum blade configurations are found by analysing these theories.

3. ANALYSIS OF THE THEORIES

The Axial Momentum Theory deals with the forces acting on the wind turbine rotor and prdicts the ideal efficiency and flow velocity, regardless of the shape of the blade. On the other hand, The Blade Element Theory calculates the forces on the blade due to its motion through air. It considers each blade's element to behave like a two dimensional aerofoil. Applying this theory to determine aerodynamic force (lift and drag) on the rotating blades and the force derived from momentum consideration are equated to have improved values of blade parameters. (The later relations are refered as The Strip Theory).

Using momentum theory, considering the effect of wake rotation, expressions for thrust and torque developed by the wind for an annulus at radius r with area, $dA = 2\pi\ rdr$ (The total swept area being the integration of this differential area) as shown in Fig.1, Ref. [4], are given by:

$$dT = 4\pi\, r\rho\, V_\infty^2\, a\,(1-a)dr \tag{1}$$

and

$$dQ = 4\pi\, r^3\rho\, V_\infty\, (1-a)a'\Omega\, dr \tag{2}$$

respectively. Expressions for thrust and torque from the Blade Element Theory, Ref.[4] are :

$$dT = (1-a)^2 \frac{\sigma C_L \cos\phi}{\sin^2\phi} \left(1+ \frac{C_D}{C_L} \tan\phi\right) \tfrac{1}{2}\rho\ V_\infty^2\ 2\pi\ rdr \tag{3}$$

and

$$dQ = (1+a')^2 \frac{\sigma C_L \sin\phi}{\cos^2\phi} \left(1- \frac{C_D}{C_L} \frac{1}{\tan\phi}\right) \tfrac{1}{2}\rho\ \Omega^2 r^3 2\pi\ rdr \tag{4}$$

respectively. Equating (1) with (3) and (2) with (4) the relations of The Strip Theory become :

$$\frac{a}{1-a} = \frac{\sigma C_L \cos\phi}{4\sin^2\phi} \left(1 + \frac{C_D}{C_L} \tan\phi\right) \tag{5}$$

$$\frac{a'}{1+a'} = \frac{\sigma C_L}{4\cos\phi} \left(1 - \frac{C_D}{C_L} \frac{1}{\tan\phi}\right) \tag{6}$$

It has been suggested in [5] that the drag terms can be omitted for calculating a and a' on the basis that the retarded air due to drag is confined to thin helical steets in the wake and have little effects on induced flow. Putting $C_D = 0$, equations (5) and (6) become :

$$\frac{a}{1-a} = \frac{\sigma C_L \cos\phi}{4\sin^2\phi} \tag{7}$$

$$\frac{a'}{1+a'} = \frac{\sigma C_L}{4\cos\phi} \tag{8}$$

Substituting these values in (3) and (4) and knowing that power equals torque multiplied by the angular speed, expression for power output is obtained.

Since optimum performance can be achieved by maximizing the power output, expressions for various parameters (for this present case, blade parameters) for maximum power output are therefore necessary. For maximum power output the relationship between a and a' found to be, Ref. [6] :

$$a' = \frac{1-3a}{4a-a} \tag{9}$$

Introducing equations (7) and (8) into this (equation(9)), the following expression yields :

$$\sigma C_L = 4\,(1-\cos\phi) \tag{10}$$

Defining the local solidity, $\sigma = BC/2\pi r$, the expression for chord comes out to be :

$$C = \frac{8\pi r}{BC_L} (1 - \cos\phi) \tag{11}$$

From the blade element velocity diagram (Fig. 2) blade twist angle is found :

$$\beta_T = \phi - \alpha \tag{12}$$

Walker [7] developed a method to use the last equations to determine the blade shapes for extracting optimum power. According to his method, the blade chord and twist angles are continuously varied at each radial element until the power coefficient has been maximized.

4. SIMPLIFIED BLADE SHAPES

Using the methods described, the blade chord and twist angle distributions are found non linear. Since wind conditions always vary with different season and location, these wind turbines with constantly varying chord and twist angle along the length of the blade are obviously not cost effective for testing purposes. Therefore, to initiate with a new wind turbine at a particular location, the design should be simple. Here a linearized blade chord and twist angle are suggested between $r = 0.5R$ and $r = 0.9R$, since distribution of those parameters within this range remain close to linear distribution.

5. RESULTS AND DISCUSSIONS

The results presented here are based on a two bladed 350 kw downwind wind turbine with tip speed ratio 8 and variable pitch. NACA 4418 airfoil section and tip loss correction modelled by Prandtle are used throughout the studies and the blade geometry is optimised to produce peak performance at 9 m/s wind speed.

In Fig. 3 radial distribution of optimum and linear chords are shown. It is found that the suggested changes in chords are very small at the outer half of the blade along the radial direction. This will lead no significant power loss, as can be seen from Fig. 4 (reference [4]) that more than 70% of the total power extracted by the wind turbine from the wind is made available by the outer half, excepting the tip of the blades. This is because of the low efficiency at smaller radii due to smaller local tip speed ratio, and at the tip due to tip losses. (This is why the chord and twist angle were suggested to linearize between $r = 0.5R$ and $r = 0.9R$) .

Radial distributions of optimum and linearized twist angles are shown in Fig. 5. The changes are also insignificant at the effective portion of the blade. Moreover, zero twist angle distribution is also shown here. With this type, design complication and hence price is further reduced. Specially for a completely new location, the blades with zero twist angle is safe for a trial operation. Once it becomes feasible, then it worths spending for its improvements.

In Fig. 6 starting torque coefficient for differnt blade shapes as a function of pitch angle are shown. With linearized chord and zero twist, starting torque fall approximately 18 to 30% respectively.

6. CONCLUSIONS AND RECOMMENDATIONS

A linear chord linear twist blade is comparable to the optimum designed blade offering a considerable reduction in manufacturing difficulties and cost. In spite of these, choice should be made on the basis of requirement and also on the basis that how much gain in cost is acceptable for a cetain rate of power loss.

A wind turbine with linearized chord and twist angle can be safely used where a low starting torque is required, that is for a fast running device, a generator or a centrifugal pump. But for a slow running device or piston pump that requires a high starting torque the effect of linearization must be taken into consideration.

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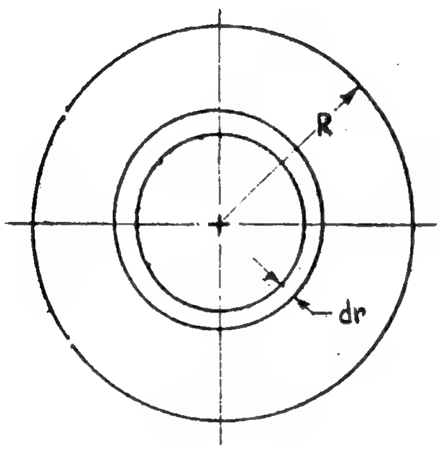

Fig. 1 : Annulus at Radius r

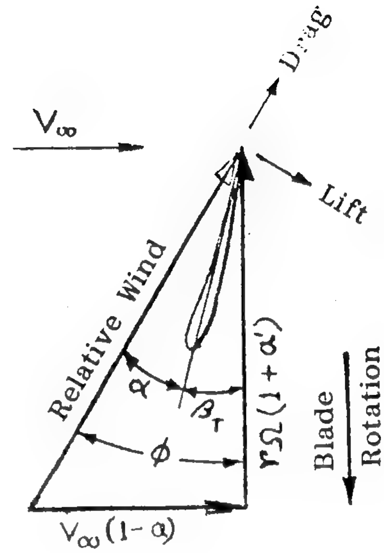

Fig. 2 : Blade Element Velocity Diagram

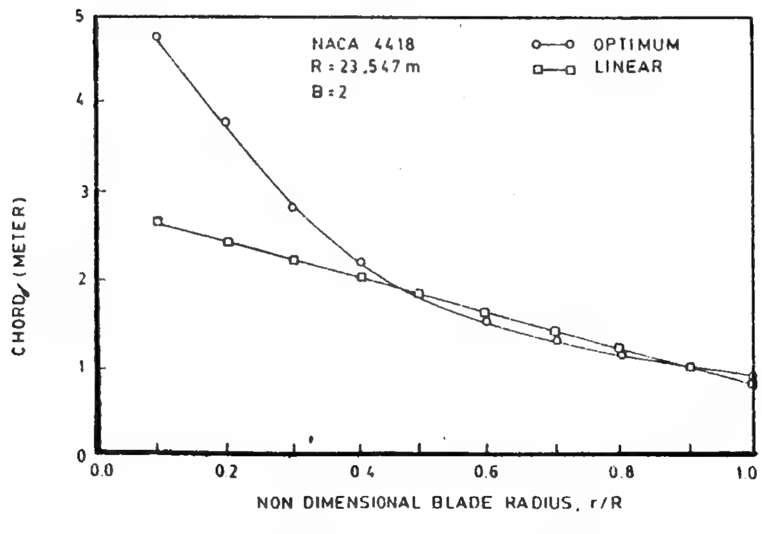

Fig. 3 : Optimum and linearized chord Distribution

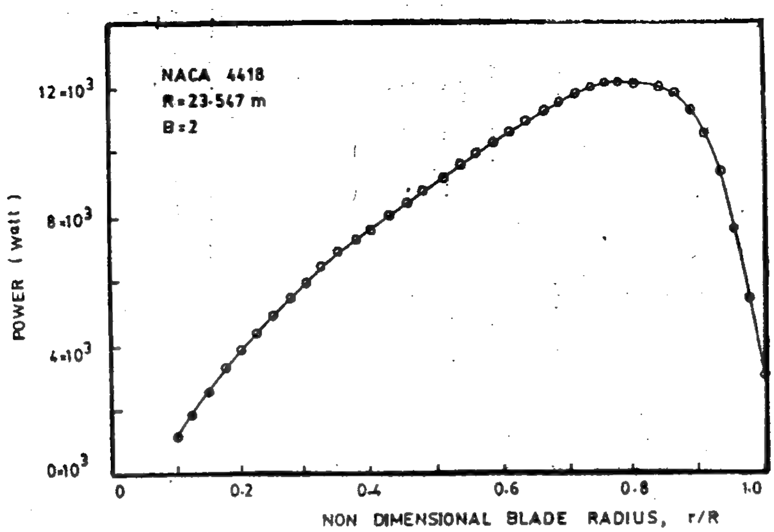

Fig. 4 : Radial Variation of Extracted Power.

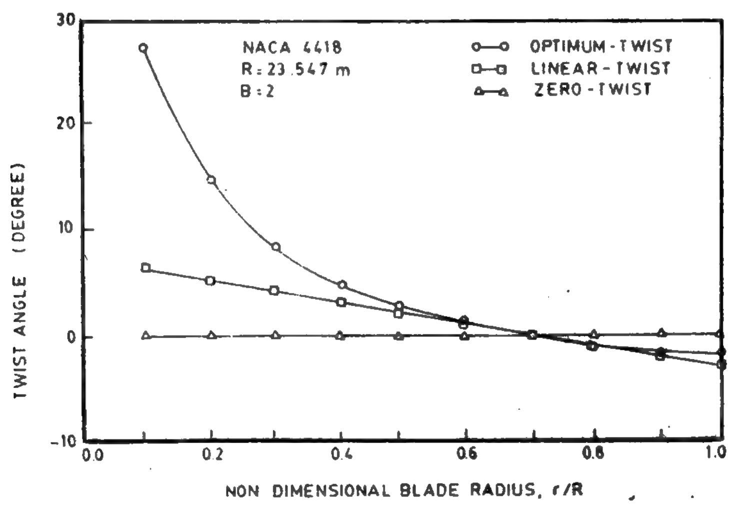

Fig. 5 : Optimum and Linearized Blade Twist Distribution

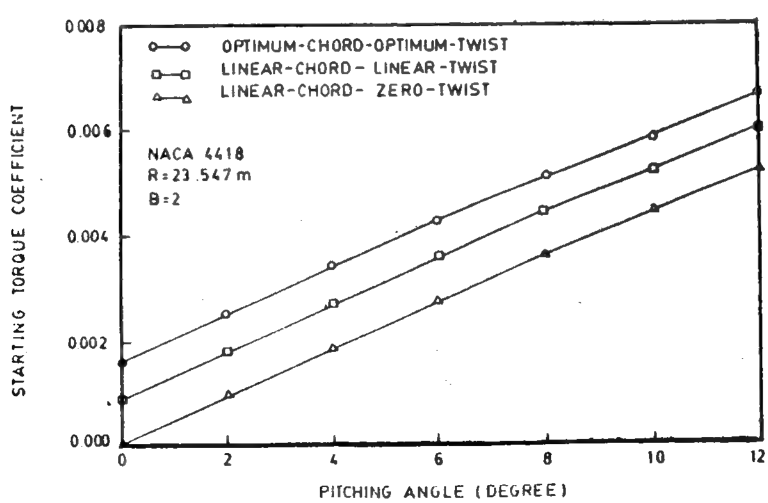

Fig. 6 : Starting Torque Coefficients for Different Blade Shapes as a Function of Pitch Angle

VERTICAL AXIS WINDMILL ASSISTED RECIPROCATING LIFT PUMP WITH HYDRAULIC TRANSMISSION

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ABSTRACT

The paper presents a simple but innocative method of using a vertical axis wind power driven turbine for a reciprocating lift pump with hydraulic transmission. This transmission is utilized to avoid the problems of alignment of gears, levers, guides etc. inherent in transmission of rotational motion of shaft to reciprocating pump. The proposed hydraulic transmission comprises of two identical cylinders made from 127mm (5 inch) diameter seamless M.S.pipe 380mm long. Each of the cylinders has a double acting piston with end ports of each cylinder being connected by two pipe lines for transfer of fluid between driving and driven cylinders.A pump with 127mm diameter bore and 300mm stroke will deliver 12 to 15 m^3 per hour at 50 rotor r.p.m. and during actual test at half the stroke , the discharge available was 8 to 10 m^3 per hour at 75 r.p.m.

Major drawback in harnessing the wind energy is its intermittency which has led to the idea of mechanical wind-assist system. Irrigation pumping with motor as prime mover can be provided with mechanical wind-assist system.

1. INTRODUCTION

The Savonius rotor is a useful windpower device because of its simplicity, though it is less efficient compared to the horizontal axis devices and has high frontal area and weight. Savonius rotor is not a pure lift dependent device and its blades/shells do not behave as conventional aerofoils.The flow field is highly unsteady and, by and large, separated. Thus there does not exist any really satisfactory theory for the Savonious rotor. A few researchers have attempted to give a potential flow model, but there calculations are not in any sense definitive.

The first and foremost disadvantage of Darrieus is non-self starting and requires a starter or a Savonious rotor to

start up. Secondly, vertical axis wind turbine extracts somewhat less of the available energy from passing wind compared to horizontal axis wind turbine. In vertical axis wind turbine, a wind energy converter can operate in low mean wind velocities of 3 to 5 m/sec. prevalent in India. One of the serious problems involved in harnessing the wind energy is its intermittency and this has led to the idea of a mechanical wind-assist system. Irrigation pumping, with rotor as prime mover, is provided with mechanical assistance from the wind.

2. TRANSMISSION SYSTEM

Vertical axis turbine using crank,figure 1, will present problems in transmission of rotational power from rotor to reciprocating pump, for pumping water from bores or wells, such as alignment of gears, levers, guides etc. Mechanical transmission from wind rotor to reciprocating pump in a well, if placed directly over the bore well, will present lesser problems, as the crank operating rod and pumping cylinder are in alignment. Though the alignment will be relatively easy but mounting of tower on a cantilever platform will be uneconomical. When tower is located away from the well, the transmission of power will require a number of bell crank levers, guides to rod in well etc. These can be a source of misalignment.

The hydraulic transmission system presents an alternative to mechanical transmission system to be used with mechanical wind-assist system.

2.1 General Layout

The general layout is shown in Fig. 1. A vertical axis wind rotor is mounted on a tower (not shown in Fig.) located at a distance from the well. The rotor drives a crank and a bevel gear with conventional bearings etc. The connecting rod connected to a Knucle joint reciprocates the piston rod, operating the double acting driving cylinder. The driven cylinder and the double acting pump form one working unit mounted on a frame and can be located inside the well or outside it, as the case may be, with the suction pipe fitted with footvalve and strainer dipped in water. The outlets at the ends of the driving and driven cylinders are connected by two pipes (14) and (15). The two cylinders (12) and (16) with pipes (14) and (15) thus form a closed hydraulic system filled with water.

3. HYDRAULIC TRANSMISSION

3.1 Construction

The details of only hydraulic transmission are further described: reciprocating mechanism on tower and double acting pump are taken as conventional design. A pump with 127 mm dia. bore and 300 mm stroke would give 22.8 cu. meter per hour at 50 rotor rpm with 60% efficiency under ideal conditions. The driving and driven cylinders of hydraulic transmission system may have the same bore and stroke sufficient to give working stroke slightly longer than 300 mm.

The piston rod of the driving cylinder has a double bucket piston (13). The left end of the piston rod passes through rubber seal, gland nut and guide, and connected to the connecting rod from crank on wind rotor. A knuckle joint (8) allows for the obliquity of the connecting rod. The cylinder has two outlets, one at each end, which are connected to pipes of about 25 mm diameter. The right end of the cylinder is closed with a cap.

The driven cylinder is identical to the driving cylinder and the piston rod has double bucket pistons at both the ends. One end of the rod reciprocates in the driven cylinder and the other in the double acting reciprocating pump, passing through the gland nuts and rubber seal packings. The pump draws water through suction strainer and foot valve (19)and pumps it into the delivery pipe (20).

3.2 Operation

The driving cylinder, driven cylinder and pipes- forming the hydraulic transmission system- are initially filled with water through a non return valve(11), after removing the air from the cylinders. When the hydraulic system is completely filled with water, reciprocation of the piston rod mechanical assist wind system causes piston in the driving cylinder(12) to move between positions P and Q. When the piston is at the position P, the piston in the driven cylinder(16) will be at P' position and the position in the double acting pump is P''. When the piston travels towards Q, water in the blanked end of cylinder is forced through pipe (14) which pushes piston in the driven cylinder to position Q' forcing water in the driving cylinder through pipe (15). This action pushes the piston in the pump cylinder to position Q'' thus sucking the water through strainer and pumping it to the delivery pipe. During this stroke the back sides of the pistons in driving and driven cylinders were filled with water displaced by pistons. During the return stroke of the piston from Q to P the piston in the pump cylinder moves from Q'' to P'' again pumping water from suction strainer to delivery pipe. The hydraulic transmission system thus transfer energy from the wind rotor to double acting pump eliminating mechanical transmission system. When the wind rotor is not operating provision to operate the crank with motor is provided.

3.3 Testing

The connecting rod was mounted on the crank of a power hacksaw with crank radius 150 mm and was run at 75 rpm. During the test the pump gave a discharge of 8 - 10 cu. meter per hr. Thus working with lesser stroke the pump is working reasonably well and at full stroke the probable discharge of 12-15 cu. meter per hour at 50 rpm is expected. The extensive test run with Savonius rotor is under progress.

3.4 Likely Problems

From the experience in operating this pump, the following problems are envisaged in the proposed application to windmill

(i) The hydraulic system has to be filled with water and pistons in the two cylinders are required to be brought to the correct working positions.
(ii) Leakage past the pistons and through glands needs be diminished as for as possible.
(iii) The system should always remain filled with water.

The first problem can be overcome with correct locations of filling and vent holes. Properly designed buckets on pistons and O- ring rubber seals on glands can minimize the leakage. A device, such as nonreturn valve with a reservoir cup to provide make up water when piston is not moving or at the dead centre positions of the driving cylinder, would help to keep the system filled with water.

4. CONCLUSION

(i) Hydraulic transmission to operate a double acting reciprocating pump for water lifting as an alternative to conventional mechanical linkages, levers, guides etc. is proposed.

(ii) Hydraulic transmission system with Savonious rotor vertical axis wind mill, particularly suited for low mean velocities, is suitable for irrigation pumping applications.

ACKNOWLEDGEMENTS

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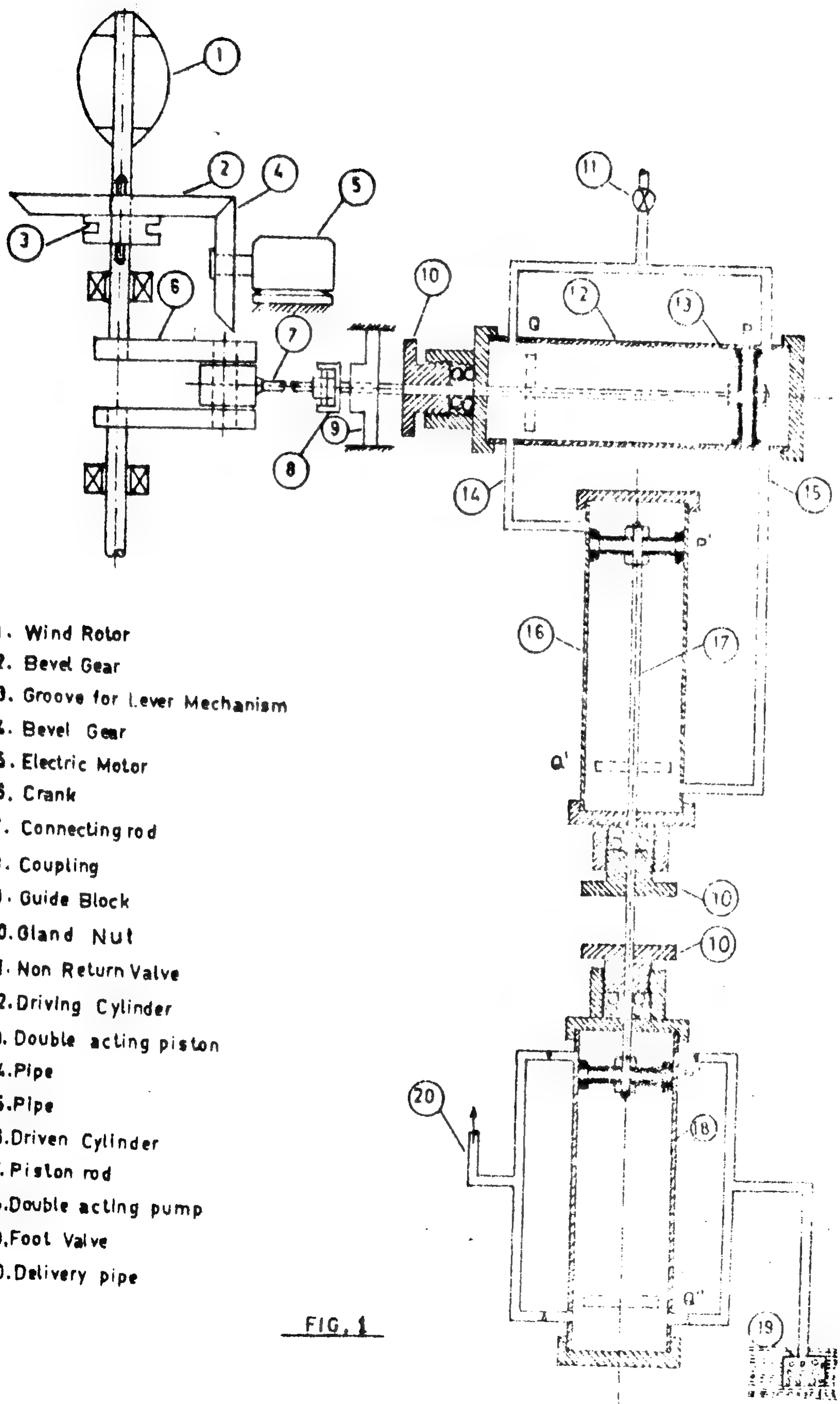

1. Wind Rotor
2. Bevel Gear
3. Groove for Lever Mechanism
4. Bevel Gear
5. Electric Motor
6. Crank
7. Connecting rod
8. Coupling
9. Guide Block
10. Gland Nut
11. Non Return Valve
12. Driving Cylinder
13. Double acting piston
14. Pipe
15. Pipe
16. Driven Cylinder
17. Piston rod
18. Double acting pump
19. Foot Valve
20. Delivery pipe

FIG. 1

GEOMETRY VARIATION OF WIND TURBINES

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1. ABSTRACT

Classically, wind turbines are designed for selected design parameters, such as : wind prevailing direction, wind speed, degree of air steadiness , wind duration and extracted power. These parameters are known to be contineously changing, and hence mean or most propable values are taken for the design purpose. Turbines designed accordingly suffer from performance deterioration at off-design conditions. If geometry variation of the wind turbine is introduced in order to match with deviations from design values, high turbine performance can be attained in all operating conditions.

In this paper a number of proposed wind turbine geometry variation techniques are presented and analysed. These techniques include the variation of: blade pitching, variable rotor orientation, variable rotor diameter and material, variable tower height, air brakes and the variation of surrounding flow field.

The practical application of some of the proposed geometry variation of wind turbines, such as the variation of rotor orientation, are already in practical use, while others are still in need for more research work to verify their feasibility for practical utilisation.

2. INTRODUCTION

The design process of a wind system is always done for certain input data, and comes out with determined output parameters. Fig(1) shows a simplified layout of the design process of a wind system.

The input data are classified into wind and load data. Wind data can be

summarised in :wind speed (V), wind relative direction (ϕ), wind speed profile [$V = f\ (x,y,h)$ - where h is the height from ground surface], wind steadiness [$V = f\ (t)$ - where t is time] and air contamination.

Load data can also be summarised in : maximum load [L_{max} in watts (power) or in meters (head)] , mean load [$\bar{L}$] , load variation profile [$L = f(t)$] , load transmission means and any special requirements.

The design process starts with mean or most propable values of these data, and defines the specifications of the wind system. these specifications are mainly : turbine dimensions, height of tower, blade aerofoil section, orientation of turbine axis, material used and mechanical integrity.

Performance of designed wind system can then be predicted either using imperical formulee or experimentally. This includes the determination of actual output power, system efficiency, system safe life, performance deterioration with life time, turbine rotational speed, vibration modes of tower and turbine , capital cost .... etc. .

The power output (P) of a wind turbine is theoretically proportional to : the cube of wind speed (V), the air density (ρ), the area swept out by the turbine (A) and the efficiency of the wind turbine (η)[1] , as given by equation number (1) :

$$P = \tfrac{1}{2} \cdot \eta \cdot A \cdot \rho \cdot V^3 \qquad \text{.....................} \quad (1)$$

Fig(2)[2], shows the power extracted from wind turbines of different diameters at various wind speeds based on the above equation assuming constant turbine efficiency. At off-design conditions, efficiency is never constant, and deterioration in turbine performance is experienced

3. VARIATION OF INPUT DATA

Wind data may vary with time, location or height. Fig(3)[3], shows an example for the variation of wind speed, wind direction and turbulance intensity with time in a bad weather front. This variation of wind speed can be better represented by the density and cumulative distributions as shown in fig (4)[4].

The general circulation of the atmospheric air is caused by the uneven heating and rotation of the earth, the Hadely cells and Rossby circulations. the Trade winds and the Tropics, the Westerlies to the north and south of the trade winds and Polar Easterlies[5]. On the other hand, time scale has its effect, such as the Monsoon circulation which is seasonal and also the Tropical cyclons. The travelling large scale weather or local mesoscale

circulations create a frame of work within which the local factors determine the local wind conditions. Local wind at a particular place and height show considerable variation in strength and direction, mainly due to local factors such as tropographic features and local small scale obstacles, buildings, trees, ridges, valleyes ...... etc.,and the properties of the underlaying surface. Heating or cooling of the underlaying surface and outside disturbances also influence the air flow.

4. BLADE PITCHING

The incidence angle of flow to the aerofoil blade cross section at certain radius depends on two main parameters, namely :wind speed (V), and blade peripheral speed (U). Fig (5) shows the velocity triangle of wind inlet to the turbine blade of aerofoil section. The angles shown in the figure are as following :

β = flow angle relative to rotating blade.

λ = Setting angle of the blade at the specified radius.

α = angle of attack.

where :

$$\lambda = \beta - \alpha \qquad \text{......} \quad (2)$$

Angle of attack (α) must be less than the stalling angle of the blade section and it should corespond to the maximum lift to drag ratio in order to ensure maximum power output of the turbine. This means that angle (α) must be kept almost constant during all operating conditions to enhance turbine performance. Hoever, angle (β) is never constant as :

$$\beta = \tan^{-1} \frac{U}{V} \qquad \text{......} \quad (3)$$

Where U is varying with the variation of rotational speed, and V is continuously changing. So, to keep angle (α) constant, the blade stagger angle (λ) must be changed so that :

$$\Delta \lambda = \Delta \beta \qquad \text{......} \quad (4)$$

This is the process named pitching. Fig (6)[6] shows the effect of pitching on the turbine performance for a wind turbine presently in operation. Blade pitching, if introduced, can also be used for the control of turbine rotational speed and for air breaking.

5. VARIABLE ORIENTATION

Maximum power can only be extracted by horizontal axis turbine when its axis coincides with wind flow direction, which is continuously changing. The wind turbine orientation needs to be changed with the change of wind speed direction to acheive optimum performance. Now in use, a flat plate fin is directly connected to the rear side of the wind turbine, so that an aerodynamic moment is produced on the common shaft if wind changes its direction. In futur more sensitive, more reliable and lighter designs are expected to be used.

6. VARIABLE ROTOR DIAMETER AND MATERIAL

At the same site, wind speed is varying seasonaly. So, a fixed geometry wind turbine is designed for the mean wind data of one season, and itworks at off-design conditions during all other seasons.Fig (7) shows the seasonal variation of mean monthly wind speed in three different sites in LIBYA (Derna, Ghdames and Tazerbo) [7].

Two or more wind turbines of different diameters and different material are proposed to be ready for installation by the variation of season. In fig (2), points A and B show that rotor diameter of 10 and 4 meters are needed to produce 1 KW power at mean wind speeds 4 and 8 m/s respectively. More study and research work is still needed to verify the feasibilty of this proposal.

7. VARIABLE TOWER HEIGHT

As mentioned in last point, wind speed profile may change seasonally (or even between day and night). A controlled tower height may put the wind turbine always at the maximum speed region. Again more study and research work is needed to verify the feasibility of this point.

8. AIR BRAKES

In case of overspeeding of the rotor due to a faulty control and/or hydraulic system, the centrifugal power may actuate a mechanism which will cause feathering of the blade tip and the rotor will rotate slowly. By means of the aerodynamic brake the rotor speed will not exceed normal rotation speeds. Fig (8) shows a sketch of an air brake.

9. VARIATION OF SURROUNDING FLOW FIELD

Power is known to be proportional to the cube of wind velocity. So, any slight increase in wind speed leads to a relative high increase in power.

Reflecting surfaces of variable inclination angles fixed at different relative locations around the wind mill will lead- if well controlled- to an increase in the effective wind speed privailing around the wind turbine. By this way, we can cover areas of low wind speeds with wind mills, and also increase wind mills output at the existing sites[8].

9. CONCLUSION

While the first airplane- flew early in this century- had only one variable geometry parameter for pitching, the modern high speed multi-purpose aircraft may have more than two hundred variable geometry parameter which ensures its high performance at all operating conditions. A similar futur, not necessarily that versatile, is expected for wind systems. However, further detailed research work is highly needed to acheive this goal.

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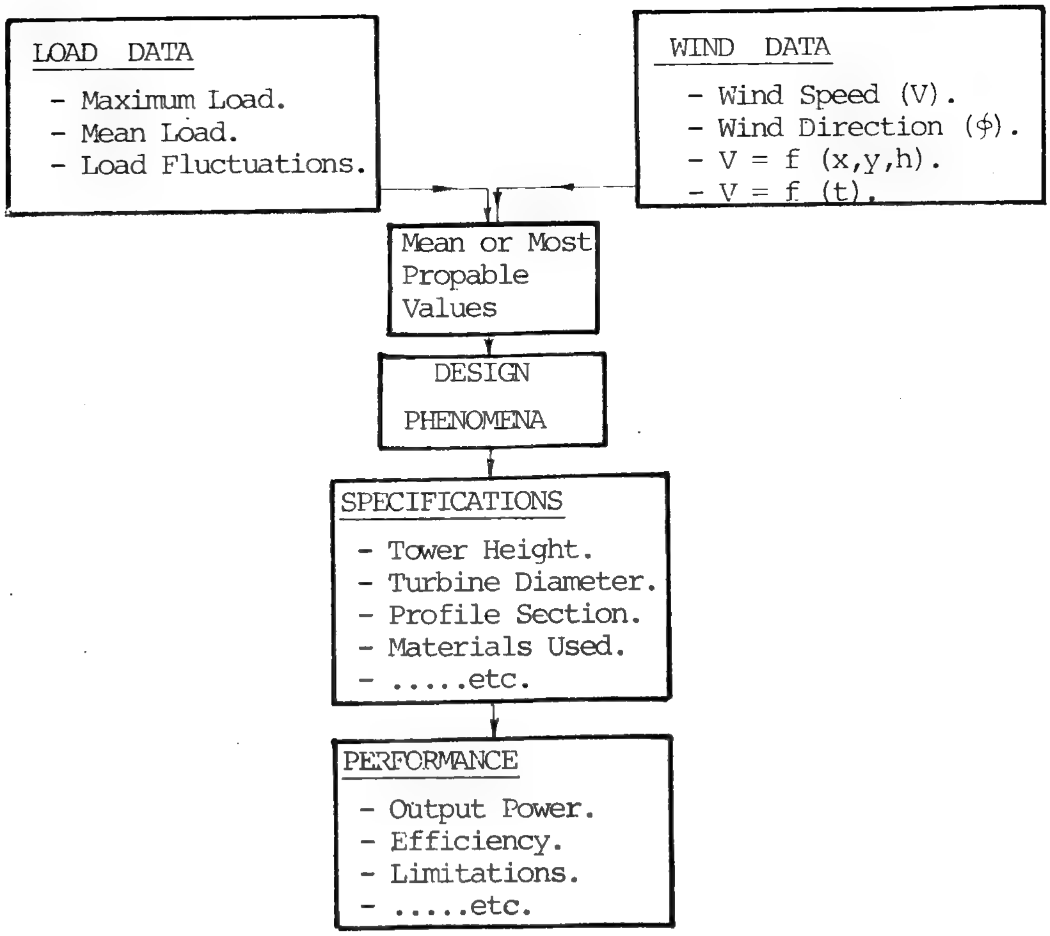


Fig (1) : Lay-out of Design Process of Wind System.

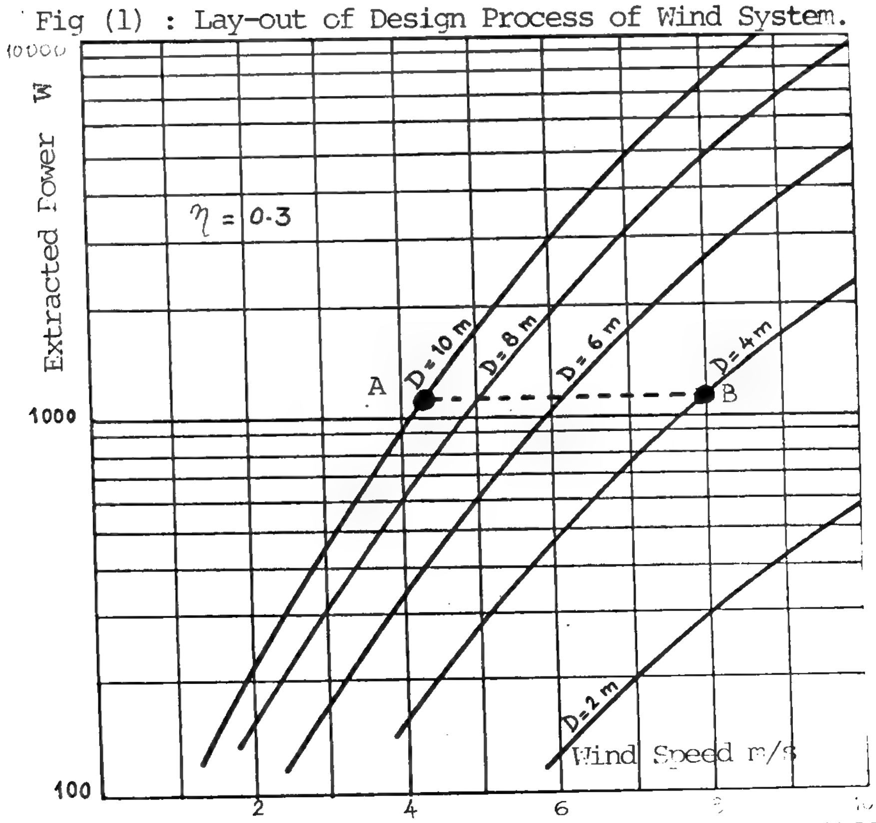
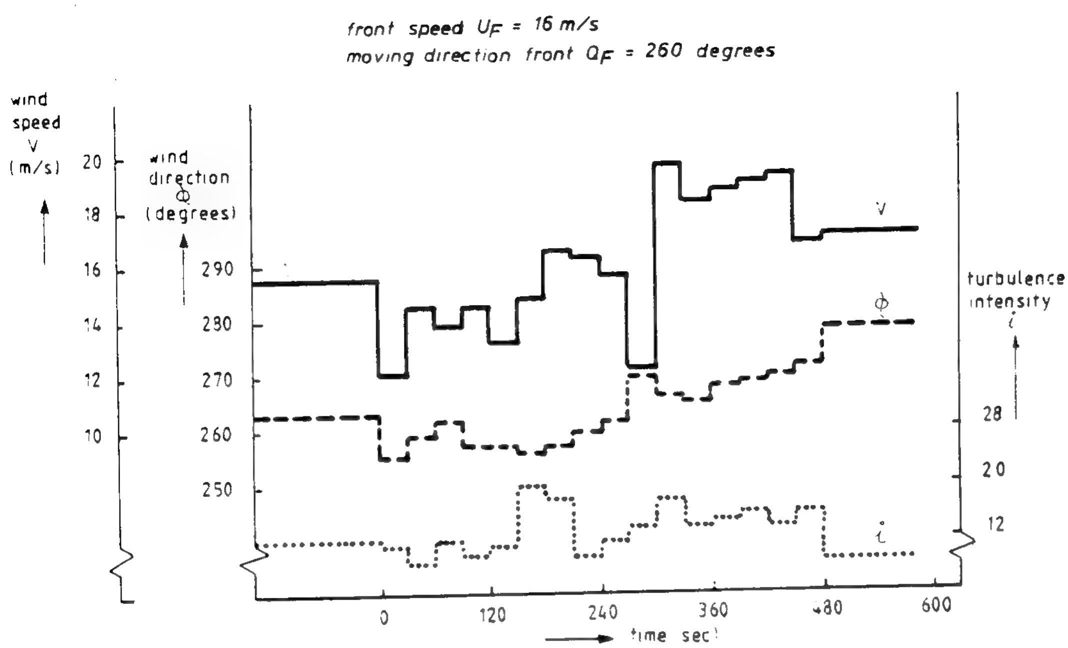
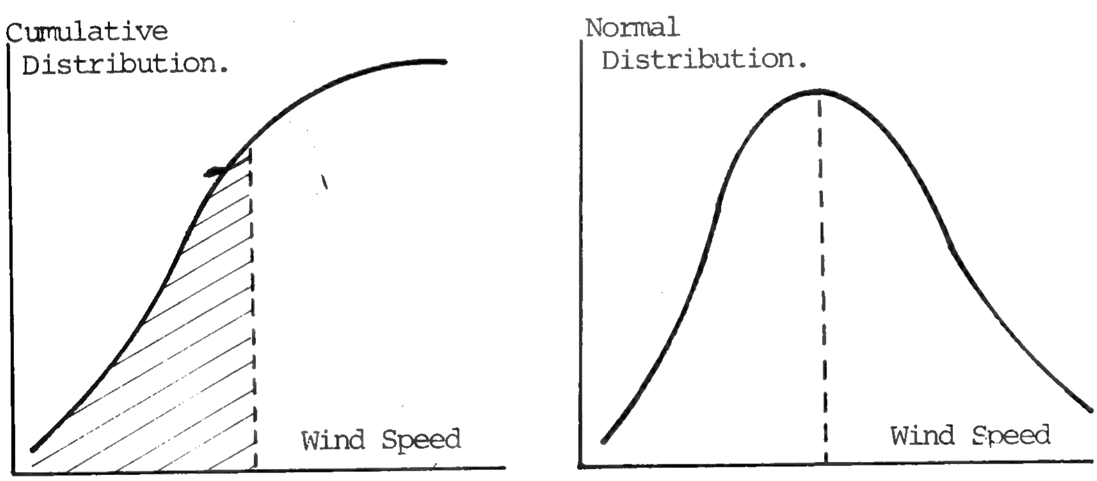


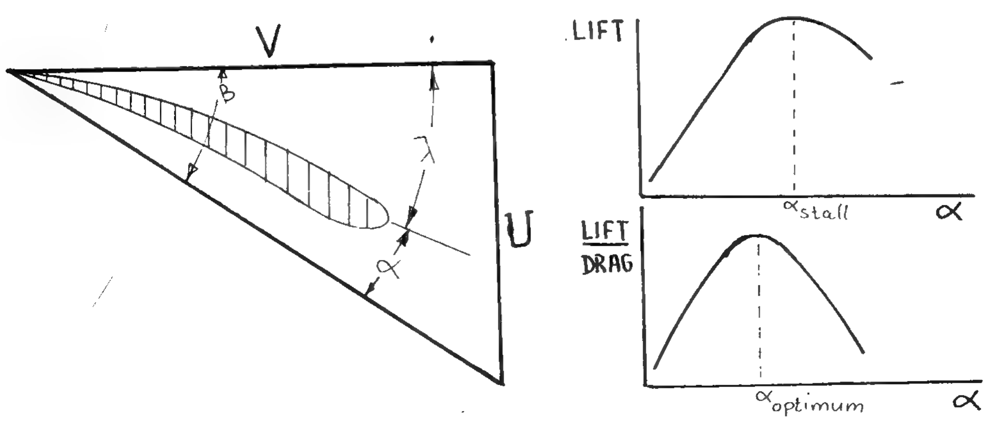
Fig (2): Power Extracted by Different Wind Systems at different wind speeds.



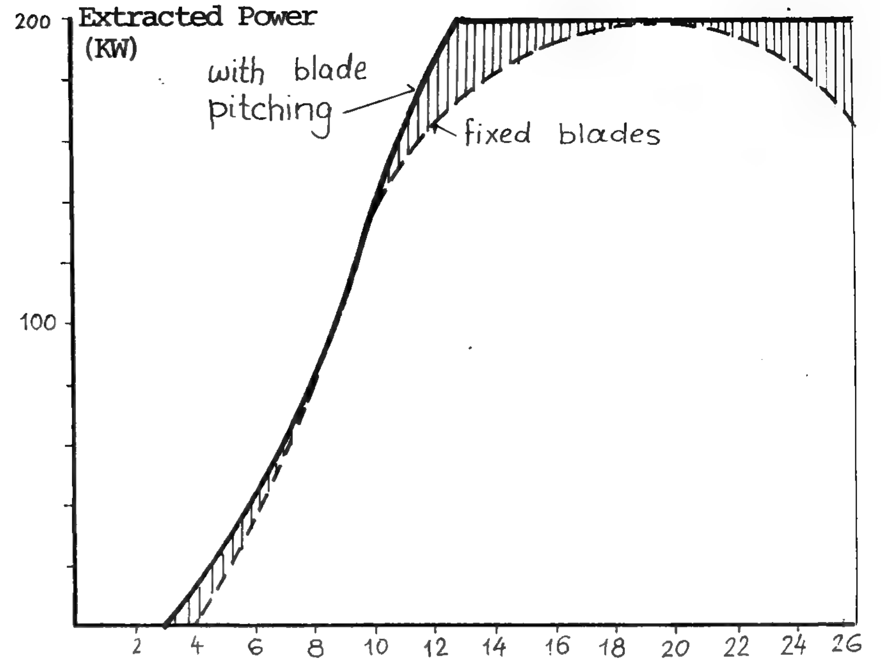
Fig(3): Variation of wind parameters in a bad weather front



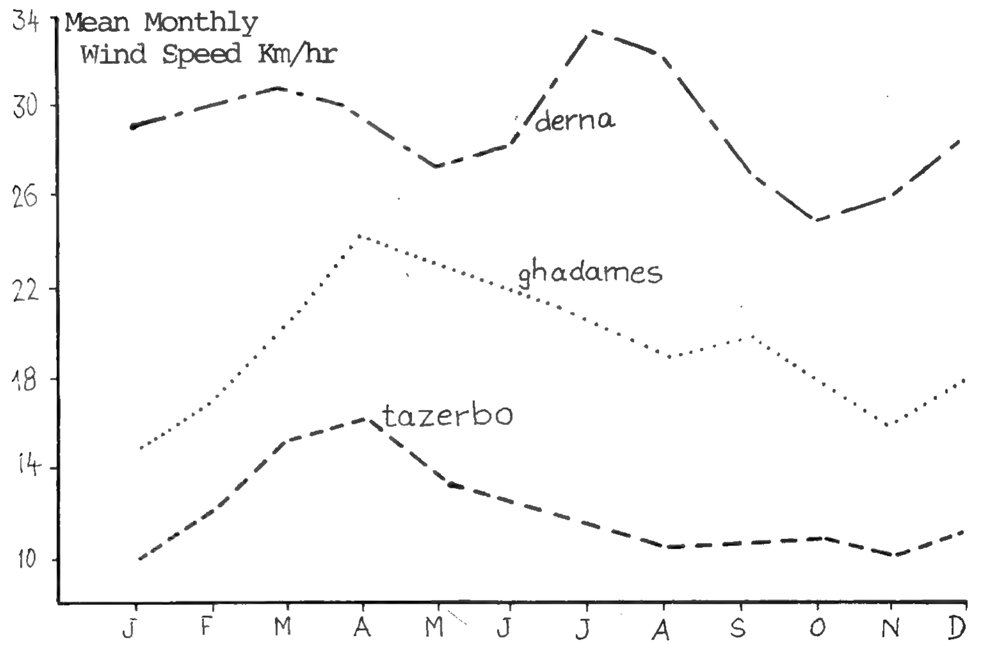
Fig(4): Cumulative distribution of wind speed.



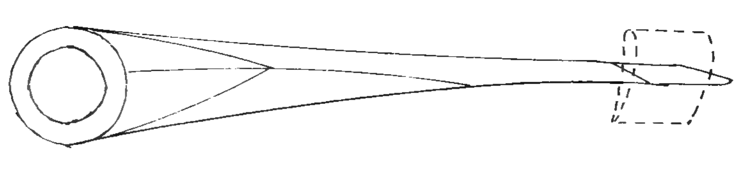
Fig(5): Velocity triangle of wind inlet to the turbine blade.



Fig(6): Effect of pitching control on turbine performance.



Fig(7): Mean monthly wind speed over ten years at Derna, Ghadames and Tazerbo.



Fig(8): Air brakes.

AN OVERVIEW OF WIND ENERGY AND ITS PROSPECTS IN BANGLADESH

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ABSTRACT

People are applying recently developed technologies for extracting wind energy more effectively. The budget of research and development in the area of wind energy is increasing every year in many developing and developed countries. The research activities for harnessing wind energy is at an infancy level in Bangladesh. The wind data collected from meteorological stations are analysed and presented here. The wind speed is satisfactory for operating pump and for generating electricity. The wind turbine may be useful to drive manually operated pumps, now, used for irrigating agricultural land. The performance of sail wing rotor coupled to a diaphragm pump is shown to be satisfactory.

INTRODUCTION

Bangladesh is a part of Indo-Bangla subcontinent. It is situated between $20^{o}34'$ and $26^{o}38$ N latitudes, and 88^{o} 01' and $92^{o}41$E longitudes with nearly 100 million people living on 144,000 km^2 area. It is an agricultural land. Its agriculture needs supply of water at right time from irrigating land. A recent study shows that 36730 low lift pumps of 12 m head and 0.066 m^3/S discharge are in operation in the field. It is claimed that there is a surface water potential for a total of 54,700 pumps of 0.066 m^3/S capacities. Recently man powered pumps have become popular for irrigation and its demand is increasing every year. Considering the terrain of the country about 50% of these pumps required to be operated at head of 6 m or less. These pumps are driven either by diesel engines or by electric motors. The installation of windmill will be convenient for operating the pumps. The domestic wind power plants may be applicable to many areas in Bangladesh. For selecting the size and type of wind machine, the information about wind speed, direction and its duration should be known (1) . The meteorological department can give the preliminary information for identifying the prospective areas of wind power (3). This paper presents the data of two meteorological stations in Bangladesh.

Mary types of rotors are in use for extracting energy from wind. The horizontal axes rotors are used in many wind pumps, even for domestic water pumping. In early 1960, many research groups put their attention to use vertical axes rotors or their combinations have been developed for this purpose, and they are (i) Savonius, (ii) Darrieus and (iii) Sail wing. The performance of rotors depend upon design, and the ratio of the rotor tip speed to the wind speed. This applies to both horizontal axis and vertical axis rotors of fixed pitch blade (1).

The performance of a sailwing rotor coupled with diaphragm pump is shown here, and a basic design of the rotor with indigenous material is given.

WIND DATA

Wird power of an area determines the size and shape of the rotor appropriate to that location. The wind data from the meteorological stations give an estimation of available wind power. The wind speed recorded by the meterclogical department in Chittagong and Coxis Bazar are shown in Fig. 1. These values are the average of the data recorded during the period 1976-1986. The average wind speed in Chittagong is 5 Knots or above throughout a day in the month of May. Sometimes this speed goes upto 10 Knots. This speec is satisfactory for driving pumps or for generating electricity of the orcer of 2 KW. In Cox's Bazar area the wind speed ranges from 3 knots to 6 knots during a day as shown in Fig. 1. This may be useful for driving shallow tubewells operating at a pump head of 6 m or less.

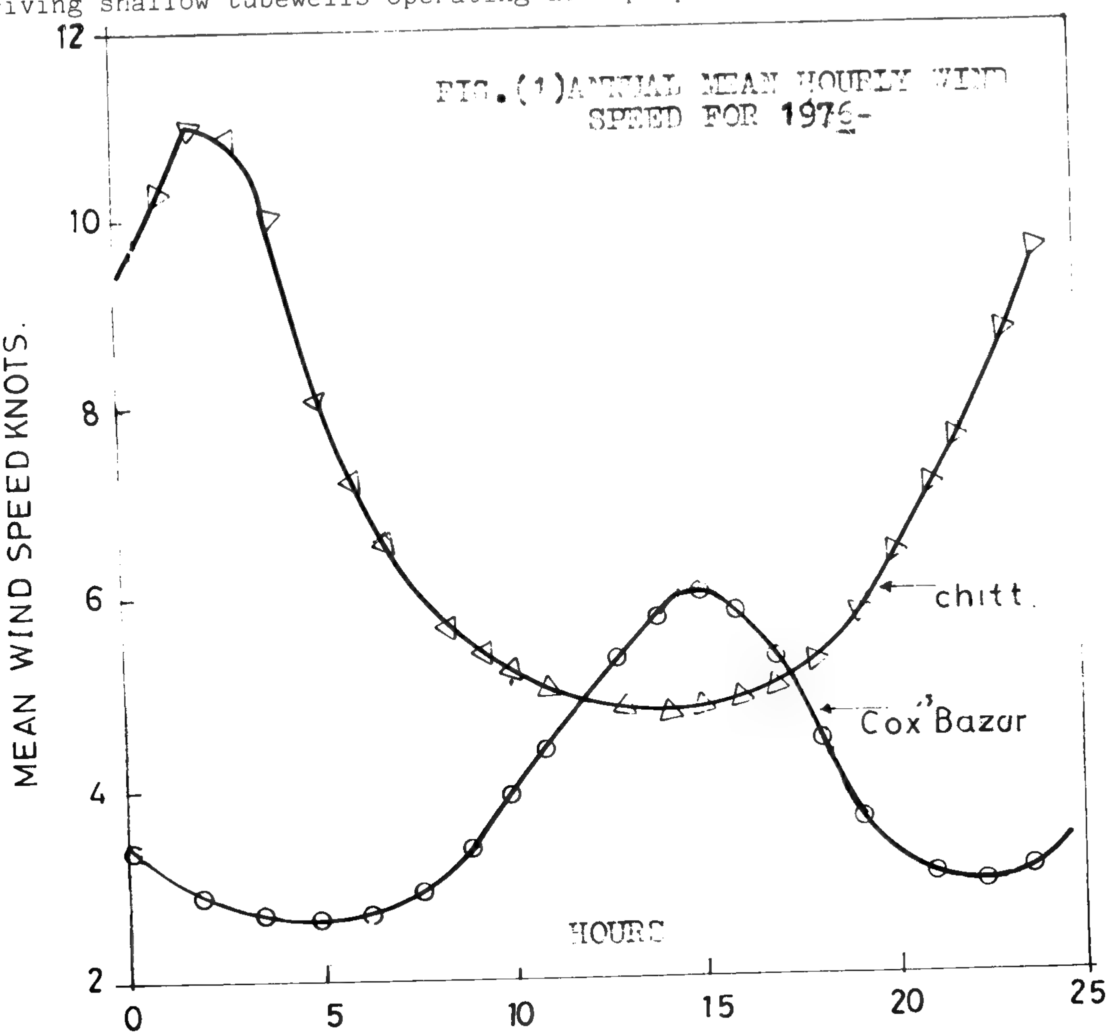


Fig. 2 shows the speed-duration curve for Chittagong and Cox's Bazar. These data are the average of values during 1976-86. Fig. 2 shows that the wind speed in Chittagong is 5 knots or more for 4000 hours a year. At this available speed a wind plant can be operated both for electricity and for driving pumps. A vertical wind rotor of swept area 100 m^2 can produce about 2 KW power at this wind speed. At Cox's Bazar area the wind speed is 5 knots or more for about 2000 hours a year as shown in Fig. 2. This speed may not be recommended for wind plant.

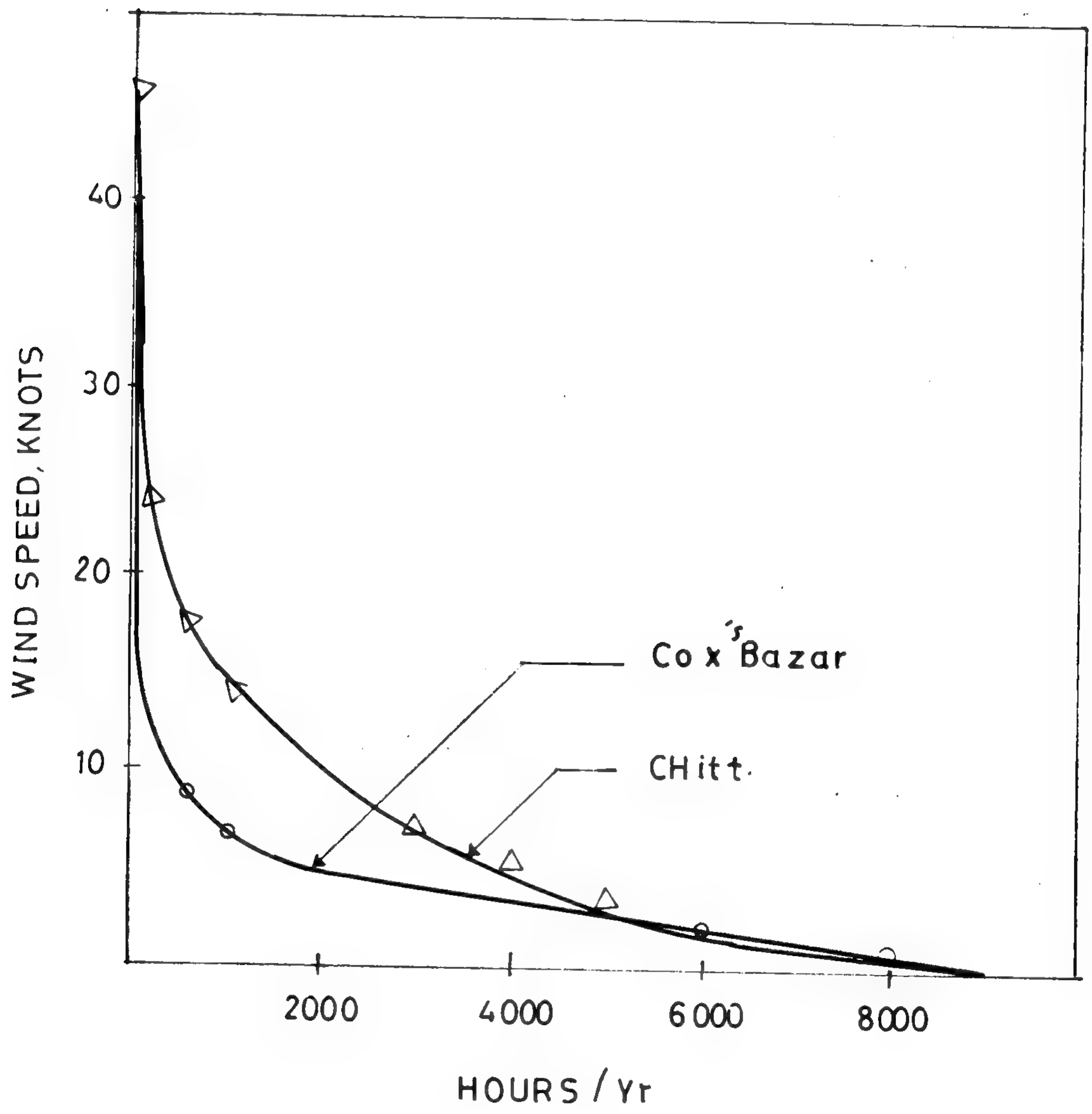


FIG. (2) VELOCITY DURATION CURVE,

The wind power per unit area of approach is proportional to the cube of wind speed, and it can be expressed as $Pw/A = 0.0577\ V^3$ where Pw/A is in watt/m^2 and V is in mph. This wind power represents the strength of wind, and theoretically maximum 59% of this power can be extracted. The wind power Pw/A is plotted in Fig. 3 to show the strength of wind in Chittagong and Cox's Bazar. It shows that the wind power 100 watt/m^2 or more for 2000 hours, in a year in Chittagong. Choosing suitable rotor size useful amount of energy can be harnessed both for electricity and for driving pumps. Fig. 3 also shows that in Cox's Bazar the wind power is about 50 watt/m^2 or more during 1000 hours in a year. This may be useful for driving shallow tube-wells for lifting water.

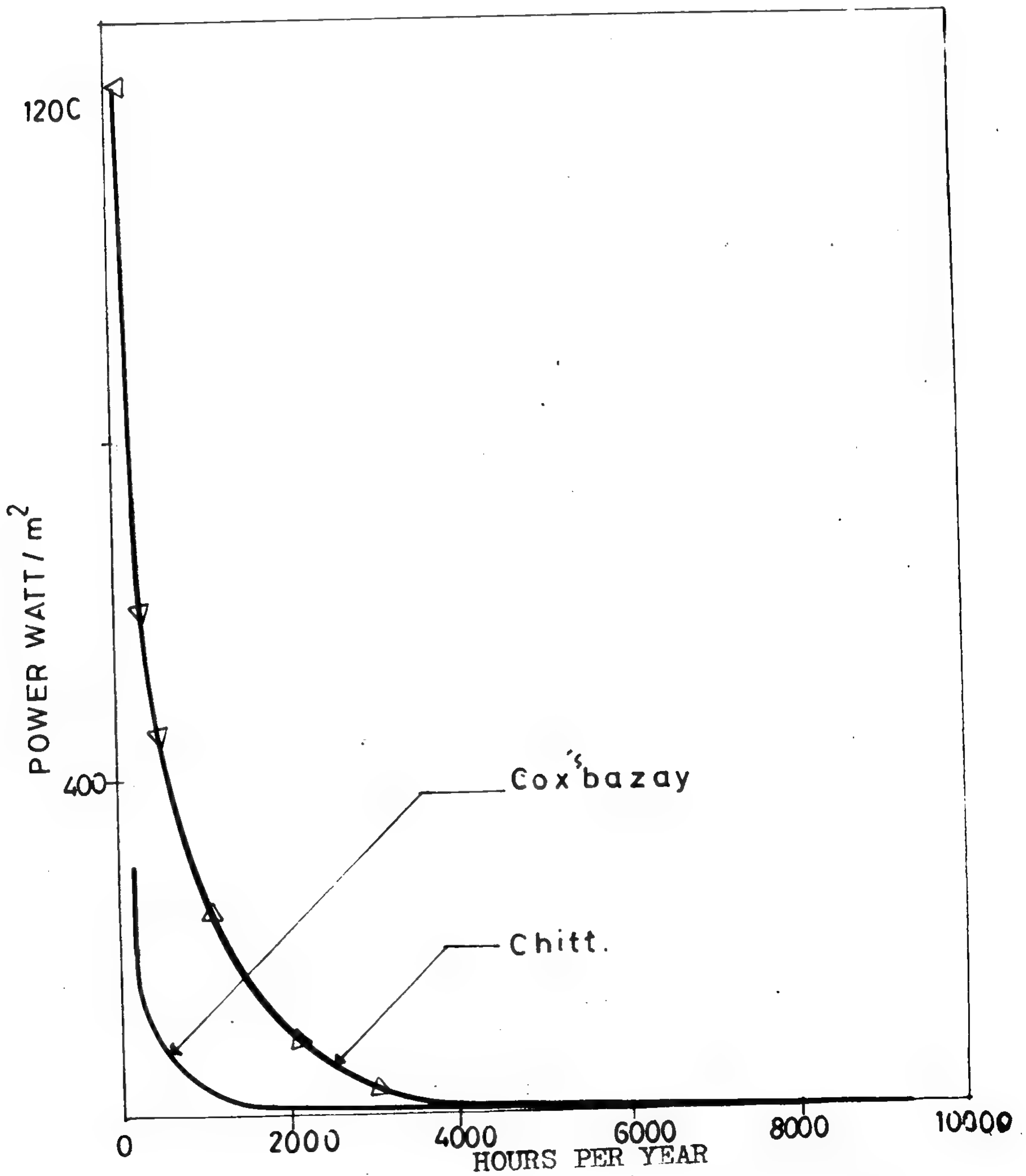
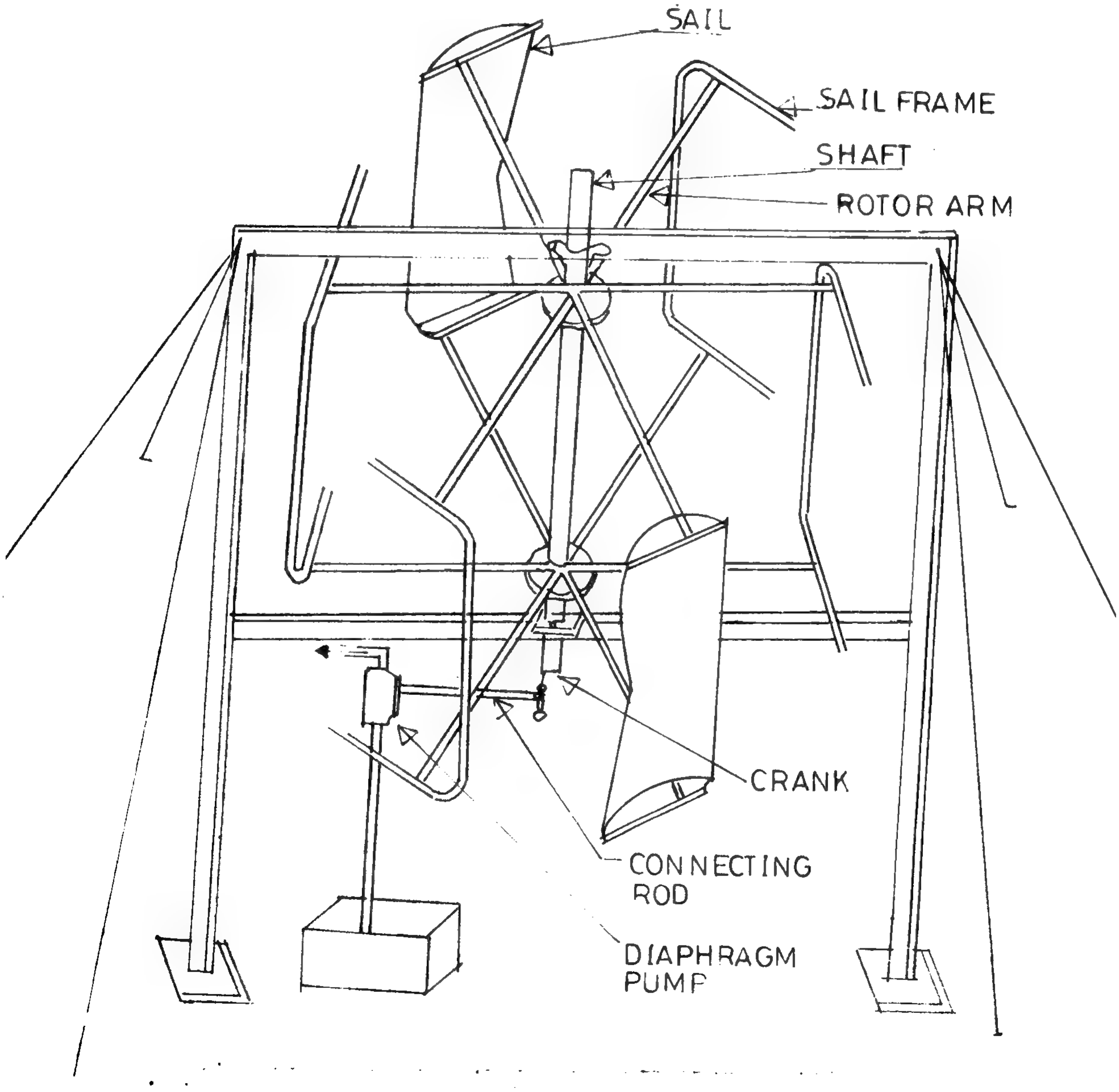


FIG. (3) WIND POWER IN CHITTAGONG AND COX BAZAR

The wind data at other twelve meteorological stations show similar strength of wind energy. So, here data from two extreme cases are cited. The wind speed is expected to be at higher order in islands and coastal areas in the country. The installation of wind powered machines at the coastal and island areas will be useful for lifting water and for generating electricity.

SAILWING ROTOR

It is an old device of vertical axis rotor, it is easy to make using indigenous material (5). A typical rotor of this kind is shown in Fig. 4 with six sail frames and sails. Six arms are equally spaced and welded to a plate of 30 cm diameter and 6.35 mm thick. The plate is fitted on the top of a 3.175 cm outside diameter steel pipe. Similarly another six are fitted, at the bottom of the pipe, on another circular plate of same type.



The length of each arm is 1.52 m. The arms are made of steel conduit pipe of 2.54 cm outside diameter and 1.59 mm thick. Six sail frames are also made of steel conduit pipe of 1.91 cm outside diameter and 1.59 mm thick. The height of each sail frame is 1.3 m and the length of its extended parts are 90 cm. Each sail is fitted to two rotor arms respectively. Six sails are made of jute sack instead of costly canvas. The dimension of each soil is 1.22 m x 0.76 m.

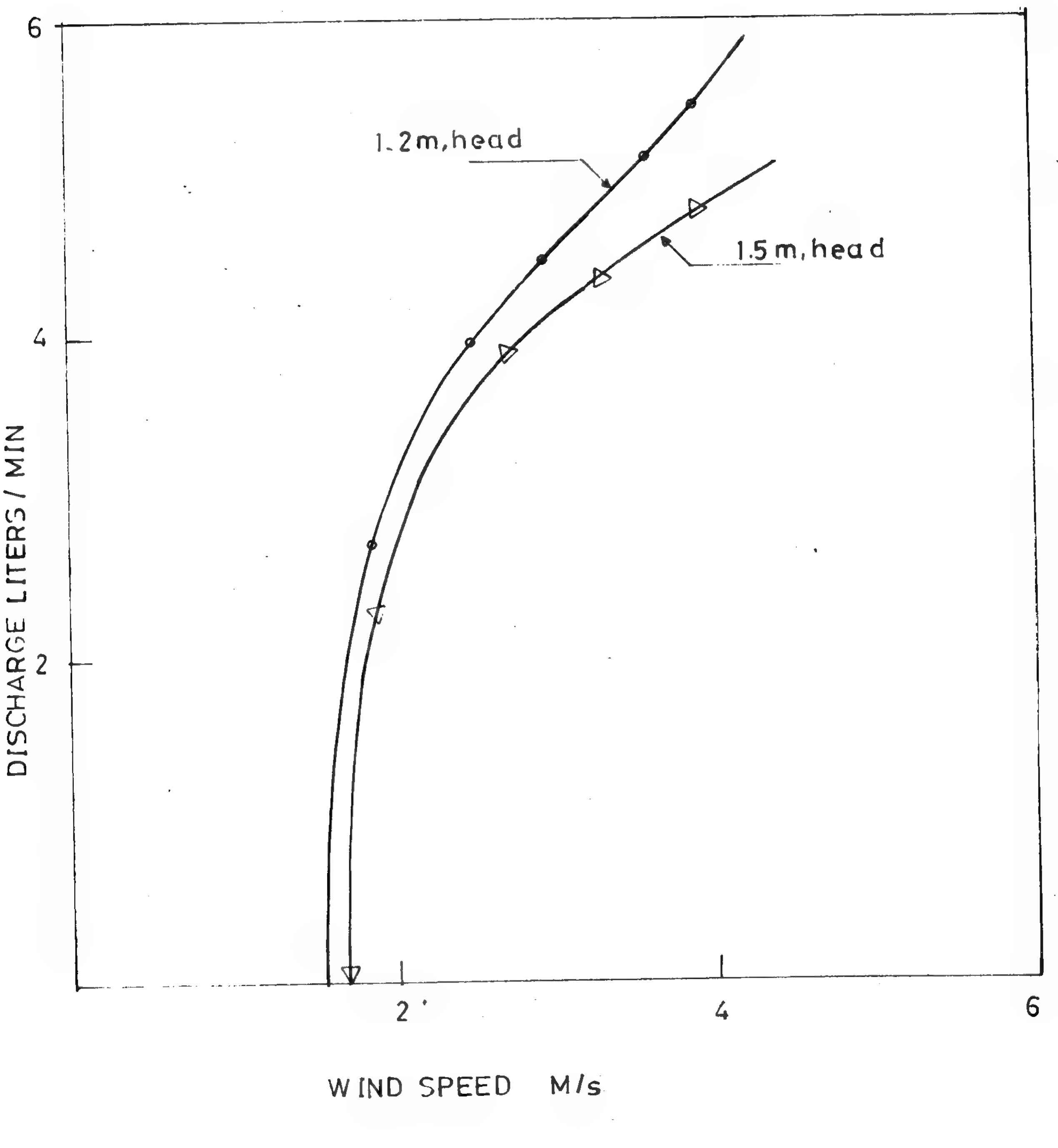


FIG.(5). VARIATION OF WATER DISCHARGE WITH WIND SPEED FOR SAILWING ROTOR.

The rotor is supported with the help of 3.18 cm x 3.18 cm x 6.35 mm angle frames and all structures are made of steel frames. A standard ball bearing is used at the top of the vertical shaft which is fastened to the cross angle frame by bearing casing and bolts. The shaft is extended through the thrust bearing by an amount of 20 cm to fit crank as shown in Fig. 4. The crank is made of mild steel rod, and it is connected to a locally made diaphragm pump. The length of stroke is 3.81 cm. The whole structure is kept in position by galvanised iron wires 1.59 mm diameter.

The rotor together with the pump is installed at a location where the wind speed did never exceed 6 mph. The average discharge of water is calculated and plotted in Fig. 5. The rotor was installed at a height of about 12 m and the pumping head was 1.2 m and 1.5 m. The performance of this unit is satisfactory. A prototype of larger dimension is expected to produce desired results for lifting water.

CONCLUSION

1. The wind data presented here are not very prospective, but its use for lifting water and for generating electricity may solve energy problem in the country to some extent.

2. In most of the areas, the pumping head is less than 6 m which is appropriate for using diaphragm pumps and the manpowered pumps. For this pumps the available wind power in the country can produce good results with a suitable rotor.

3. The use of locally available materials and technology can produce satisfactory wind pumping unit for lifting water.

4. The sailwing rotor made of indigenous materials coupled to a diaphragm pump gives a satisfactory discharge for its application.

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WIND TURBINES COMBINED WITH ENERGY STORAGE

by

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ABSTRACT

In cases where wind turbines are connected to power systems and the power demand is higher than the peak power output of the turbine, all the energy produced by the turbines can be utilized directly.

In many rural areas and isolated communities the power demand is relatively low compared to the power which can be produced by modern wind turbines. The output might exceed the power demand, and the surplus power production has to be dumped, or the output must be limited by a control system. Consequently, the overall efficiency of the wind power plant is reduced.

By combining the wind turbine plant with an energy storage, the surplus power production can be stored and used during periods with excessive energy demand. Thus, the overall efficiency of the total system is increased.

In this paper the energy output from a system including a wind power plant combined with energy storage and/or a diesel gen-set is analyzed as function of the storage capacity and the rated power of the diesel gen-set.

1. CALCULATION MODEL

1.1 Power system

The energy flow for a power system consisting of a wind power plant, diesel generator set and an energy storage has been calculated using the following assumptions:

(i) Wind turbine plant
The power output P is a linear function of the wind speed between the cut-in wind speed and the rated wind speed. Between rated wind speed and cut-out wind speed the power output is constant. The input for the calculation model is the cut-in wind speed V_1, the rated wind speed

V_2, the cut-out wind speed V_3, and the rated output of the turbine plant P_{wr}. Due to the fluctuation in the wind speed the power output of the turbine will also fluctuate. The calculation model takes these fluctuations into account, and the fluctuation ΔP in percentage of the power output is input for the calculation model. The power curve and the fluctuations are illustrated in Fig. 1.

(ii) Diesel gen-set
The fuel consumption B is a linear function of the load X as shown in Fig. 2. The no-load consumption "a" is a function of the rated power of the diesel engine and is equal to 1/3 of the full load consumption. "b" is the marginal fuel consumption. One diesel gen-set unit is considered in the calculations.

(iii) Storage
The energy storage is specified by the capacity Sc, efficiency of charging C_{p1} and efficiency of discharging C_{p2}.

1.2 Modelling load and wind

(i) Load
The diurnal load is specified as mean values hour by hour. The load is assumed to be the same each diurnal during one month .

(ii) Wind Speed
The one-hour mean wind speed is calculated assuming that the wind speed frequency distribution is a Weibull distribution characterized by the parameters A and k. The wind speed is generated by a probability transformation based on a random variable with a uniform distribution between 0 and 1. Ref. (1).

1.3 Operation modes

The power system operates in one of five operation modes:

A: Single generation of turbine
The surplus power production by the wind turbine is stored or dumped if the storage is full.

B: Power supply from storage only
Power production during periods with no wind and power demand less than max. power output from the storage.

C: Single operation of diesel-set
Production during period with no wind power and no energy in the storage.

D: Parallel operation of wind turbine and storage

E: Parallel operation of wind turbine and diesel-set

It is assumed that the required power quality is maintained by the control system.

More detailes regarding the calculation model is given in Ref. (2).

2. ANALYZED SYSTEMS

A number of power systems with different combinations of wind turbine capacities, storage capacities, rated power of diesel gen-set, and power demand have been analyzed by using the calculation model.

The power systems, which all include wind turbines have been analyzed in order to estimate the energy output in relation to a specified power demand. The following systems have been analyzed.

(I) System consisting of a wind turbine only

(II) System consisting of a wind turbine plant and an energy storage

(III) System consisting of a wind turbine plant, energy storage and diesel generator set

(IV) System consisting of wind turbine plant and diesel generator set.

The detailed specifications for the systems are given in Table 1. The power demand and the wind speed frequency distribution are identical for all the analyzed cases. The diurnal power demand, which is assumed to be the same during the year, is shown in Fig. 3. The wind speed frequency distribution at hubheight is assumed to be a Weibull distribution with the parameters A = 8.0 m/s and k = 2.0. This corresponds to an annual mean wind speed equal to 7.1 m/s.

Two storage capacities have been considered for the analysis. The capacity of the smallest storage corresponds to 25% of the diurnal energy demand and the biggest storage corresponds to 50% of the diurnal demand.

Also two capacities of diesel generator set are analyzed. The smallest capacity corresponds to the lowest average power demand during the diurnal, and the biggest capacity corresponds to the highest diurnal average demand.

It is assumed that cut-in wind speed, rated wind speed, cut-out wind speed, and power fluctuations are independent of the rated power of the wind turbine plant.

3. RESULTS

For each system the ratio between the net energy output and energy demand has been calculated as function of the wind turbine output, storage capacity, and rated power of the diesel generator set. The results are shown in Fig. 4.

Sufficient energy compared to the demand can only be obtained with a system including a diesel gen-set with a capacity equal to the maximum load (curve III b). If no diesel gen-set is included, nearly sufficient energy can be obtained if the energy production by the turbine is approx. 1.5 - 2.0 times the energy demand, and an energy storage with a capacity of more than approx. 8 hours of demand is included in the system (curves IIa, IIb). A doubling of the storage capacity gives only a small percentage of increase in net energy output.

Curve no. I indicates that the energy demand cannot be met only by a wind turbine. This is due to the fact that wind speeds below the cut-in wind speed will occur in 20-40% of the time (depending on the wind speed frequency distribution).

As the storage capacity is limited, power produced by the wind turbine is dumped if the wind turbine power output exceeds the demand, and the storage is full. The amount of dumped energy is a function of the wind turbine output as indicated in Fig. 5. If no storage is included, approx. 40-50% of the wind turbine energy output is dumped if the total energy production corresponds to the total energy demand. If a storage capacity corresponding to a few hours of consumption is included, the dumped power is reduced to 5-10%, and the overall efficiency of the turbine is increased.

4. CONCLUSION

According to the analyzed examples, up to approx. 90-95% of the power demand can be supplied by a wind turbine including an energy storage. In that case the energy production by the wind turbine must be approx. 1.5 - 2 times the energy demand, and the capacity of the storage should correspond to approx. 0.1% of the annual energy demand. The overall efficiency of the turbine is however low, as 30-50% of the wind turbine energy production is dumped. If the energy production of the wind turbine is between approx. 40% and 100% of the energy demand, the dumped energy is reduced to approx. 0% to 5% of the production. Below 40% all the energy produced by the turbine is utilized, either directly or via the storage.

A system consisting of a wind turbine plant and an energy storage can meet a part of the power demand. If the total energy output of the wind turbine plant is in the same order as the total demand, up to approx. 80% of the demand can be supplied by the wind energy. By combining the system with a diesel gen-set with a capacity corresponding to the maximum load, the demand can be met 100%.

The optimal system configuration from an economical point of view depends on the actual wind conditions, the investment cost of wind turbine, storage and diesel gen-set, diesel fuel cost and the requirement for power availability at any time.

An estimation of the production cost per kWh by a combined power system has been made in Ref. (3). Based on an example where the storage is a high level water reservoir, combined with a hydro power station, the production cost per kWh is between 11.7 cents/kWh and 14.5 cents/kWh using the costs given in Table 2. The corresponding production cost per kWh for a diesel power plant is in the range between 10.6 cents/kWh and 14.4 cents/kWh. In this example 100% power availability has been assumed. If for instance, 80%

power availability is acceptable, the production cost per kWh is expected to be lower than the estimates given above.

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Table 1 - Specification of analyzed power systems.

SYSTEM	WIND TURBINE PLANT					ENERGY STORAGE			DIESEL GEN-SET		
No.	V_1 m/s	V_2 m/s	V_3 m/s	P_{wr} kW	ΔP %	Sc kWh	C_{p1}	C_{p2}	P_{dr} kW	a kg/h	b kg/kWh
I a	4	13	25	100	10						
b	4	13	25	200	10						
c	4	13	25	400	10						
II a	4	13	25	100	10	540	.9	.9			
b	4	13	25	200	10	540	.9	.9			
c	4	13	25	400	10	540	.9	.9			
d	4	13	25	100	10	1080	.9	.9			
e	4	13	25	200	10	1080	.9	.9			
f	4	13	25	400	10	1080	.9	.9			
III a	4	13	25	100	10	540	.9	.9	45	3.8	0.17
b	4	13	25	200	10	540	.9	.9	45	3.8	0.17
c	4	13	25	400	10	540	.9	.9	45	3.8	0.17
d	4	13	25	100	10	540	.9	.9	135	11.5	0.17
e	4	13	25	200	10	540	.9	.9	135	11.5	0.17
f	4	13	25	400	10	540	.9	.9	135	11.5	0.17
IV a	4	13	25	100	10				45	3.8	0.17
b	4	13	25	200	10				45	3.8	0.17
c	4	13	25	400	10				45	3.8	0.17

Table 2 – Example. Comparison of costs (USD) used for calculation of production cost per kWh. Ref. (3).

	Hydro-power	Diesel gen-set	Wind turbine
Investment costs per KW (USD)	2-2,500	450	1,300
Useful life of equipment (years)	35	15	20
Capital recovery factor	1.1037	0.1315	0.1175
O&M costs (fraction of investment)	2%	3.5%	2.5%

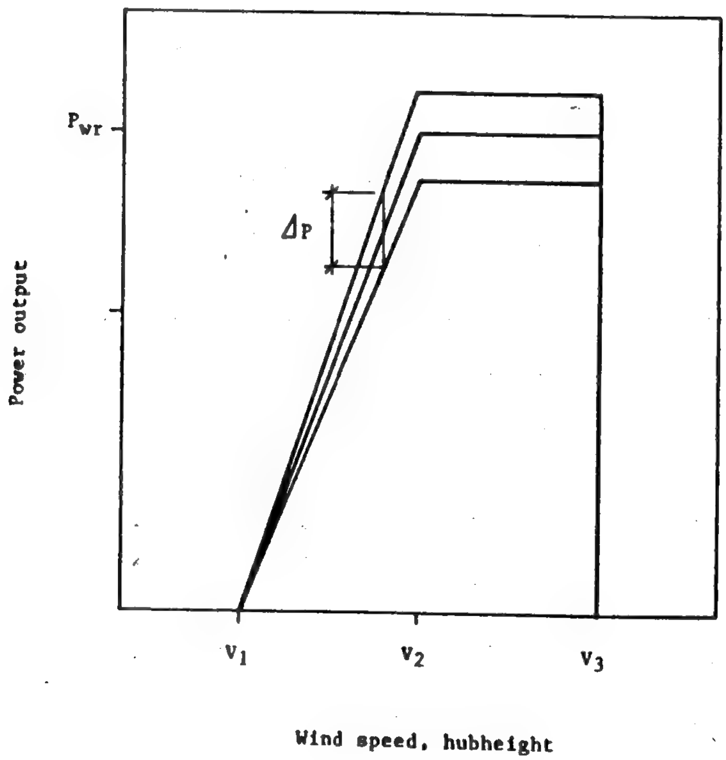

Fig. 1. Simplified power curve of a wind turbine. Power fluctuations ΔP are indicated.

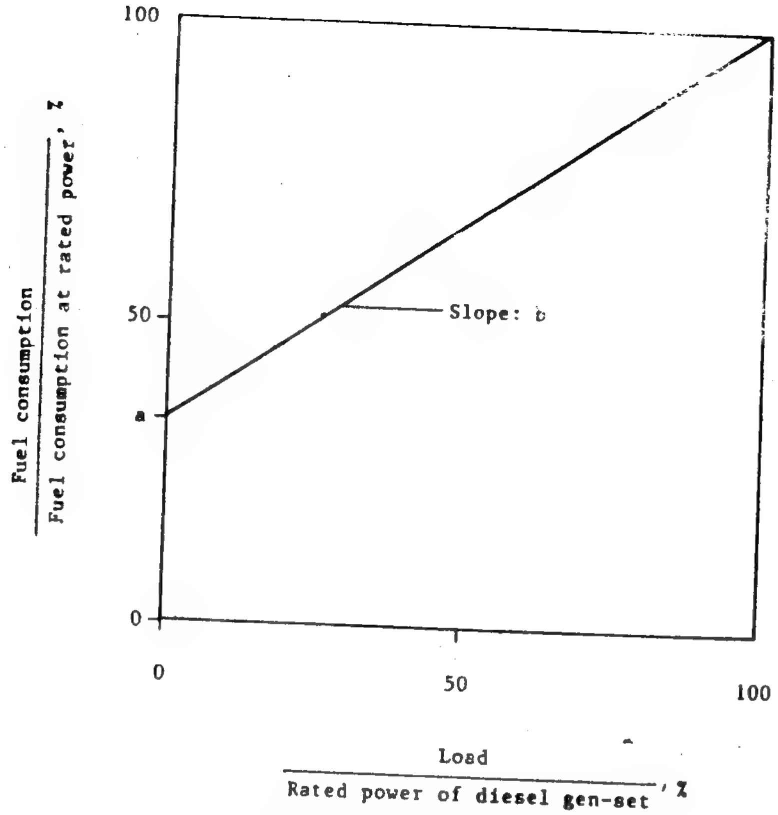

Fig. 2. Fuel consumption curve for diesel generator set.

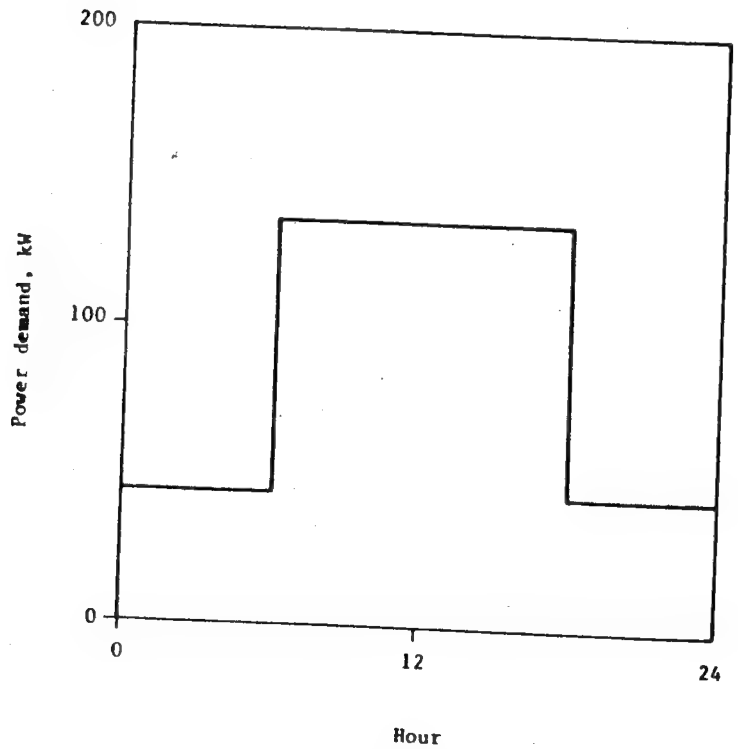

Fig. 3. Diurnal power demand.

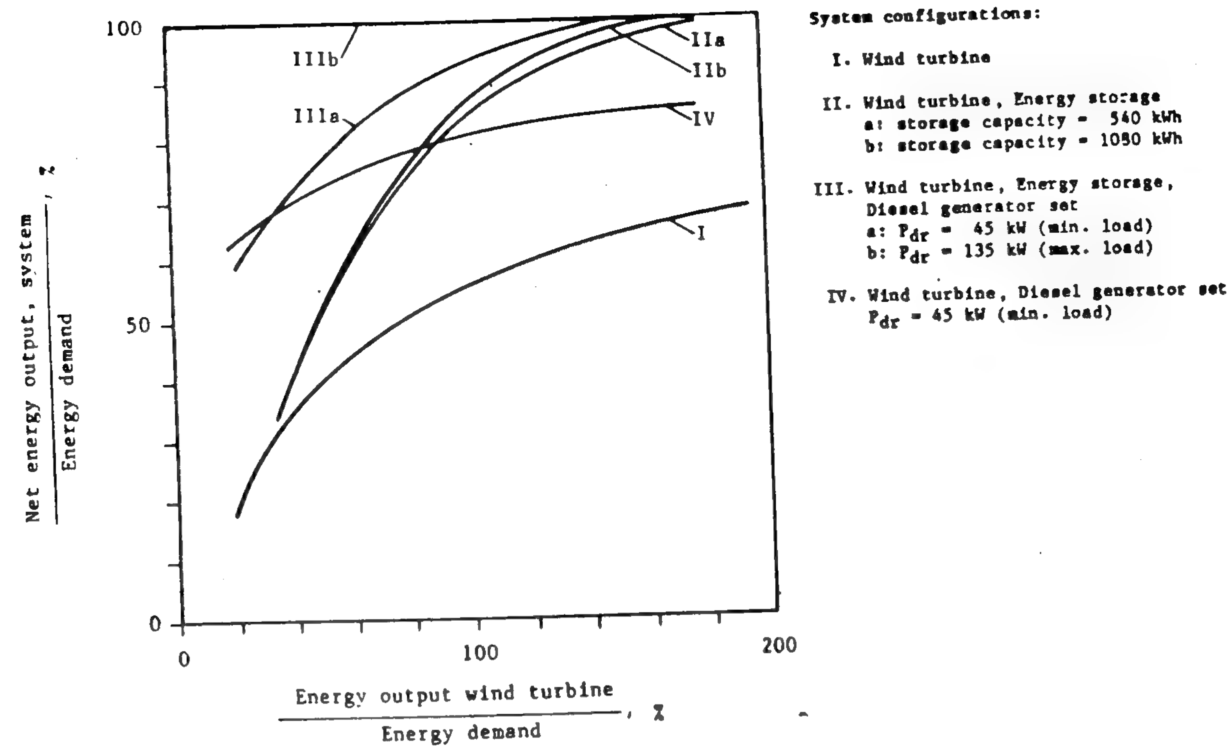

Fig. 4. Net energy output from different configurations of energy systems.

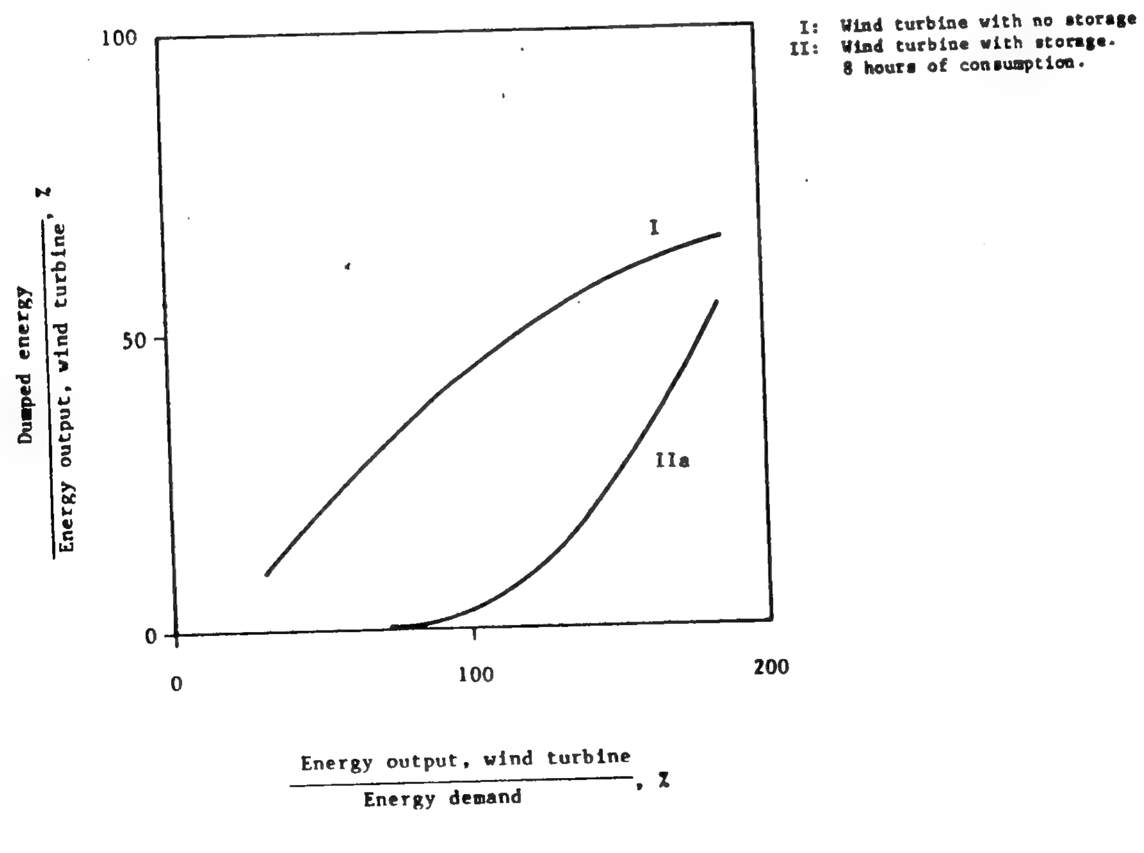

Fig. 5. Dumped energy as function of energy output from turbine and capacity of energy storage.

SECTION XVI

NUCLEAR ENERGY

SOME STRUCTURAL PROBLEMS OBSERVED IN THE CLADDING ELEMENTS FOR THE NUCLEAR PLANTS

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ABSTRACT

In the equipment of the nuclear power plants consists of many subassemblies made of the low-alloy steel cladding by the austenitic stainless steel. In cladding process the precipitation of the intermetallic and interstitial phases can be observed. This phenomenon causes the reducing of the period of safe exploitation of the plants.

There are prepared the cladding elements in accordance with the Interatomenergo prescriptions and theirs properties are examined using the destructive and non-destructive methods. The structures of each layer with the optical microscope, electron transmission and scanning microscopes are investigated as well as X-ray diffractometer and microprobe analyser.

1. INTRODUCTION

Structural materials being used in PWR primary coolant circuits include low-alloy chromium-molybdenum and chromium-molybdenum-vanadium low-alloy steels with the addition of niobium as well as austenitic chromium-nickel and chromium-nickel-molybdenum stainless steels stablized with titanium or non-stabilized. The problems connected with material strength, but especially those of economic background on the one hand and still improving processes of low-alloy steels cladding with austenitic, stainless steel filler metals on the other hand, have resulted in the equipment made of monometallic materials being replaced by that constructed form clad material. As far as the

PWR systems are concerned such items of equipment include reactor vessels, pressurizers and steam generator headers.

The corrosion-resistant lining deposited by welding remains in contact with the reactor coolant which is why its resistance to the coolant action determines the durability and reliability of the primary circuit as a whole. The selection of filler metal as well as continuous perfectioning of welding process and post-welding treatment are of crucial importance in improving the quality of the equipment of clad construction being applied in the primary coolant systems.
So far the properties and quality of clad elements have found a scarce reflection in the professional literature, mainly due to the problems encountered in the experimental work. This paper is devoted to the research on, and analysis of, how the properties of weld-metal cladding layers are influenced by their metallographic structure.

2. REQUIREMENTS TO BE MET BY CLADDING LAYERS

The cladding layers of the equipment operating within the primary coolant circuits have to satisfy a number of requirements concerning:

1. mechanical strength at service temperatures complying with the specified values as set forth in the relevant codes and documentation,
2. resistance to fatigue and thermal shocks /due to a long service life/,
3. good corrosion resistance in the reactor environment, particularly to stress corrosion and intercrystalline corrosion,
4. good properties within the ionizing radiation field,
5. freedom from strongly activating and/or long halflife period elements,
6. good nuclear properties, i.e. a low neutron absorption cross section,
7. good technological properties from the standpoint of weld-metal cladding deposition,
8. good thermal properties.

According to the mandatory codes and recommended production practices [1] both the filler materials and clad elements have to be subjected to a variety of examinations and tests, covering the certification testing to determine the tensile strength, impact strength, creep strength, low - cycle fatigue strength, corrosion resistance testing /with particular attention being paid to stress - and intercrystalline corrosion/, metallographic structure examination, and physical testing to determine the coefficients of linear expansion, thermal conductivity and elasticity. [2].

Said examinations and tests should be performed on the weld deposits in both as-welded condition and after heat treatment whose parameters are the same as those to be applied to the production elements.

3. MATERIALS USED IN THE PRODUCTION OF CLADDING

The selection of materials to be used in the production of cladding should be based on a comprehensive analysis of the parent and filler material properties with due consideration being given to the cladding deposition process [3]. The main factors governing the selection of materials are:

1. magnitude and distribution of stresses induced by static and dynamic loads taking into consideration the permissible range of elastic strain /rigidity of the structure/,
2. corrosive and erosive action of the coolant,
3. range of operating temperatures as well as magnitude and frequency of thermal variations,
4. cladding - depositing technology including the parameters of welding, heat treatment and plastic working.

Which is why the materials have to meet the specific requirements as mentioned in chapter [2].

The parent materials most commonly utilized in nuclear power engineering include low-alloy, chromium-molybdenum and chromium-molybdenum-vanadium structural steels, the former steels being also niobium treated. The alloying elements are added to increase the strength properties. Chemical compositions and strength properties of certain steel grades of this group being applied in the nuclear power engineering are listed in Tables 1 and 2.

The stainless steel cladding layers are deposited by welding on the surface of low alloy steel product. Sheets are covered with a layer having 1.0 - 1.5 mm in thickness whereas plates are usually given two layers of cladding with a total thickness ranging from 4 to 100 mm. The multi-layer cladding ensures a better tightness of the lining and provides better conditions for controlling the metallurgical processes occuring in the molten metal while the weld metal is being deposited.

Filler materials used in the process of surfacing may have the form of metal-or powder electrodes, wires or strips. The selection of filler material is governed by the surface configuration of the element to be clad and predetermined porcess of weld deposition. High productivity has been obtained with the use of stainless steel strips from 30 to 120 mm wide. The chemical compositions of certain strips are given in Table 3.
The fluxes being applied in SAW and ESW processes show strongly varying compositions, and the recommendations of their makers should

be followed in deciding the kind of process they are suitable for.

4. WELD METAL DEPOSITION TECHNOLOGY

The cladding of nuclear power equipment is most commonly performed by using arc-welding methods, including:

1. manual arc-welding with shielded electrodes /SMAW/,
2. TIG welding,
3. plasma arc-welding /PAW/ with consumable electrode,
4. submerged-arc welding /SAW/ with: single welding wire; several wires situated at right angles to the direction of weld-metal deposition; two wires including current and currentless one; welding strip.
5. electro-slag welding /ESW/ using a welding strip.

The basic factors deciding upon the selection of surfacing process are the productivity, degree of parent metal and cladding layer intermixing and the quality of cladding surface. The latter factor is of vital importance in the production of equipment for nuclear power engineering.

The selection of welding parameters should ensure:

1. minimum welding stresses produced by uneven shrinkage of parent material and deposited metal during the solidification of the latter,
2. minimization of deposited metal defects, particularly of those inducing a notch-effect /porosity, craters, fusion discontinuities/,
3. minimization of defects occuring at the deposited metal edges due to an intensive cooling at welding pool boundaries /undercuts, lack of edge-fusion, slag inclusions/.

The Authors' investigations were performed on the plates of K22MA steel grade /see Table 1/, 90 mm thick.
The cladding was made in two layers deposited by SAW process with the use of strip electrode 60 mm wide and 0.5 mm thick [4]. The first layer was made with SWO7H25N13 strip and the other one with SWO8H19NIOG2B strip /see Table 3/.
The flux used was of 48-OF-10 grade. The parent material surfacing was performed at 800 A and 25 V.
Since the surfacing process was that to be used in the production of PWR vessels all examinations and tests were performed necessary for the verification of its correctness.

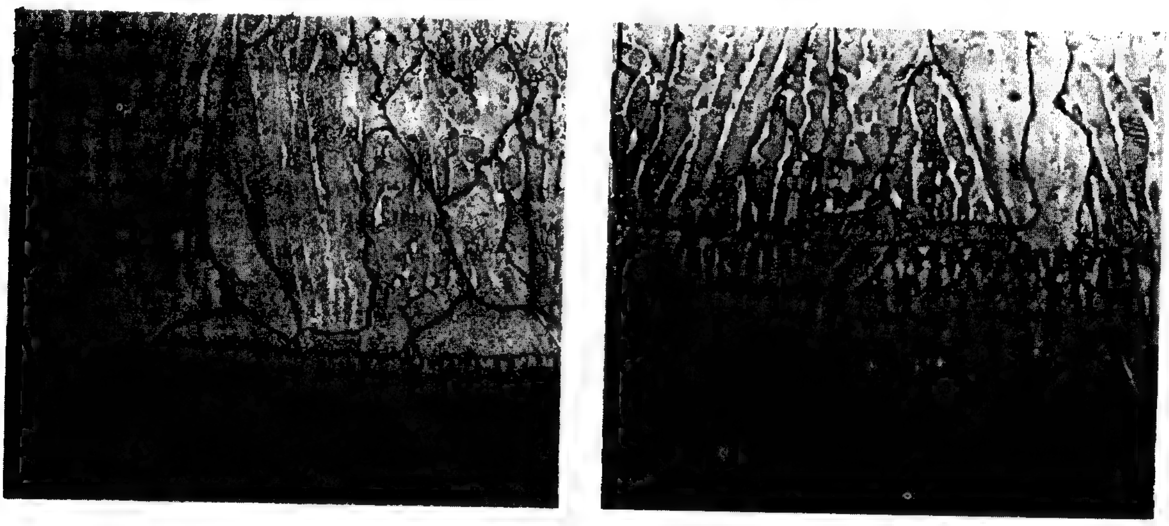
The surfaces to be clad were premachined and subjected to non-destructive examination by magnetic-particle, dye-penetrant and ultra-

-sonic methods, the examinations being repeated on completion of cladding and after heat treatment.
The test elements with 10 mm weld-metal cladding were tested for metallographic structure, hardness, ductility, shear strength, tearing strength, and resistance to intercrystalline corrosion. Check was also performed for the occurence of cracks just below the deposited metal layer. Some results of said tests will be quoted in the further text of this paper.

5. STRUCTURE OF DEPOSITED LAYERS [5]

Structure examinations were conducted on test specimens obtained from the cladding made by the process as described in chapter 4. The parent plate was of K22MA grade; the first cladding layer consisted of SWO7H25N13 material whereas the second, face layer was made using SWO7H19N10G2B strip. No material flaws were found.

Metallographic examination has revealed the presence of a transition zone occuring between the parent material and austenitic weld deposit. The thickness of the zone can vary to a large extent with the welding parameters as applied. For the sake of example the cladding with extreme width of transition zones has been shown in Fig.1.



a b

Fig. 1. Cladding structure within transition zone:

a - narrow transition zone
b - large transition zone

/etching with 10% solution of oxalic acid/.

The examination conducted by linear X-ray microanalysis has shown the minimum diffusion occuring between the parent material and

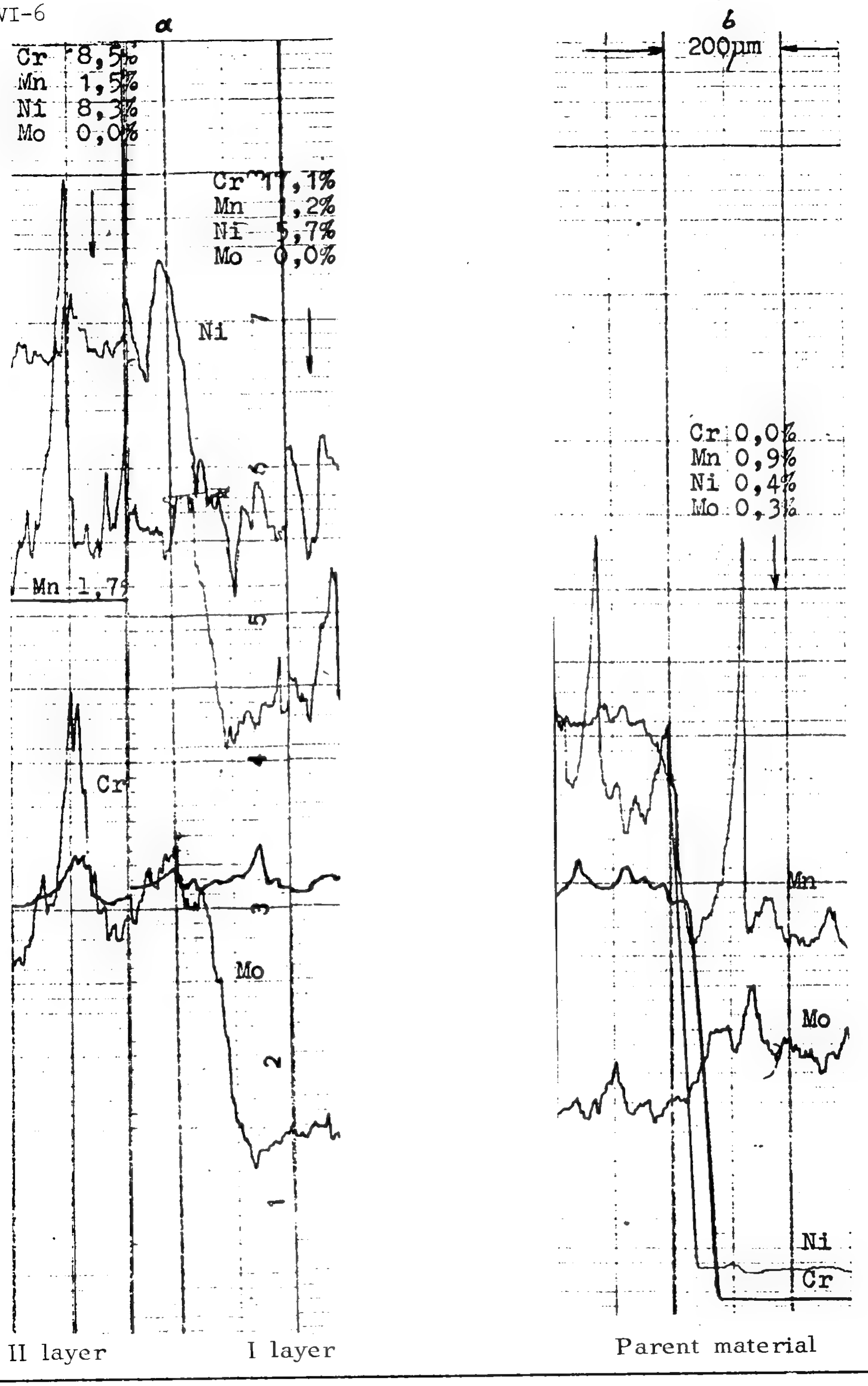


Fig.2. Linear distribution of Cr, Mn, Ni and Mo within boundary areas
a/ cladding layer - parent material,
b/ I layer - II layer.

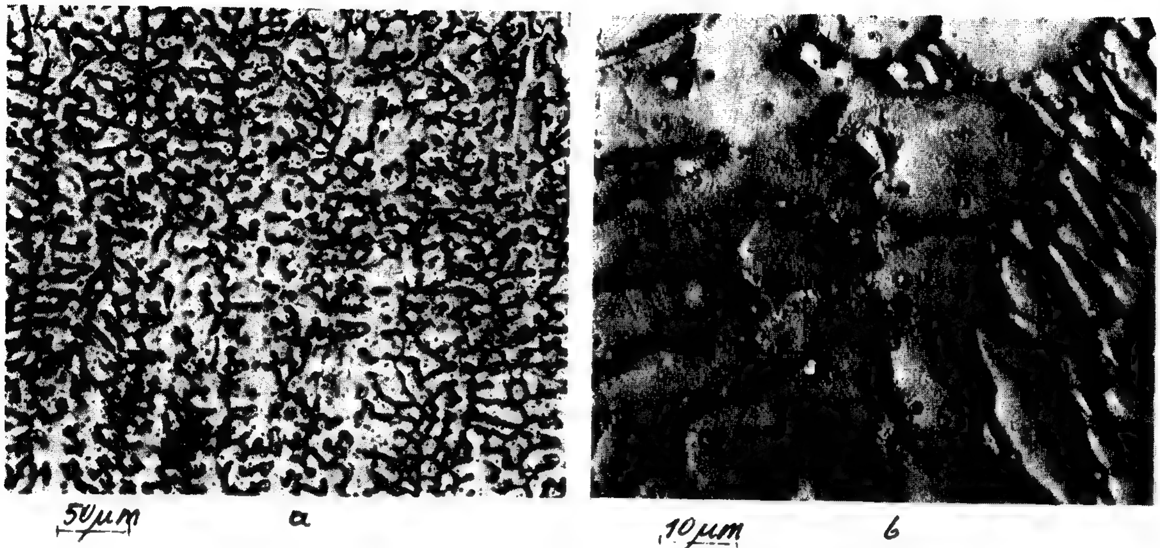


Fig.3. Dendritic structure of weld-metal cladding layer
a/ structure: general view
b/ structure: enlarged fragment.

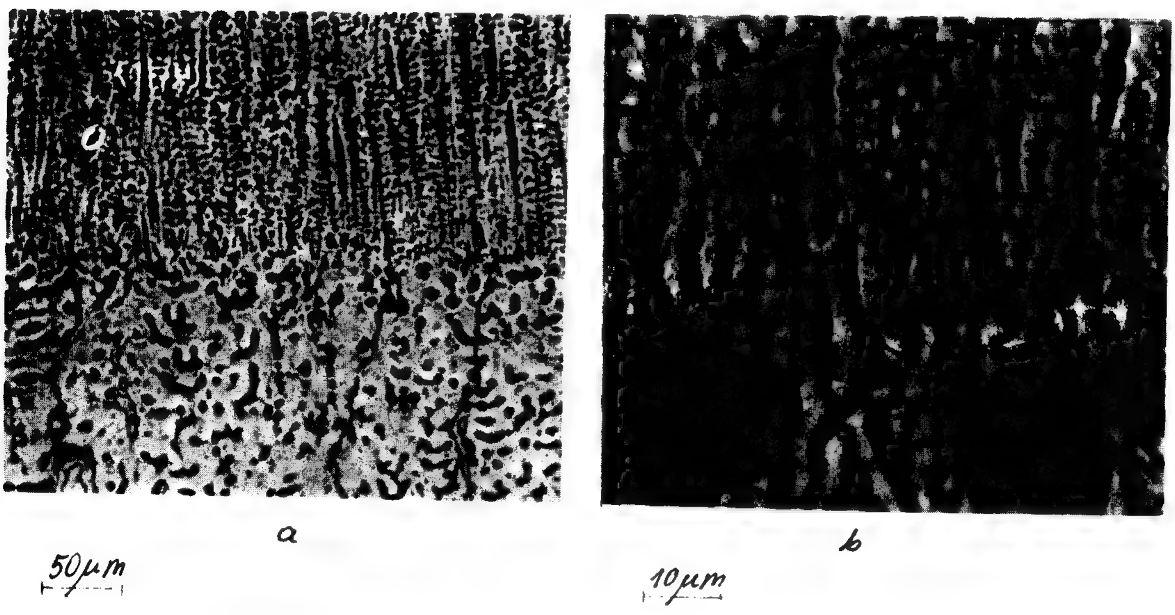


Fig.4. Structure of transition zone without interpenetration
a/ structure: general view
b/ structure: enlarged fragment.

Etchant: 10% solution of oxalic acid.

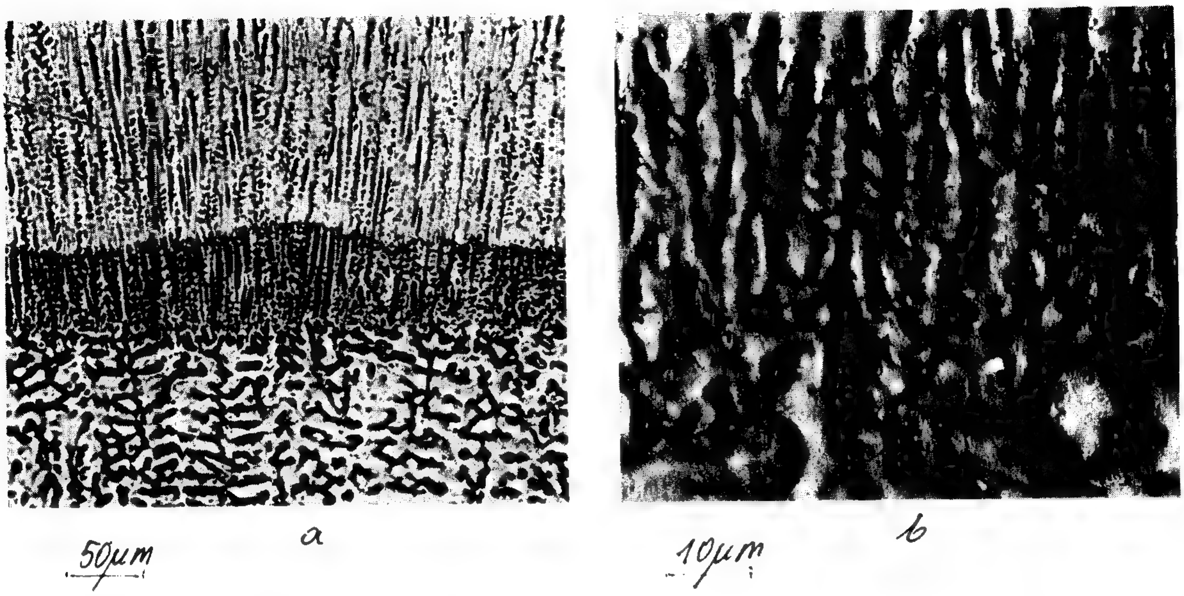


Fig.5. Structure of the transition zone between the 1st and IInd layer
a/ structure: general view
b/ structure: enlarged fragment.
Etchant: 10% solution of oxalic acid.

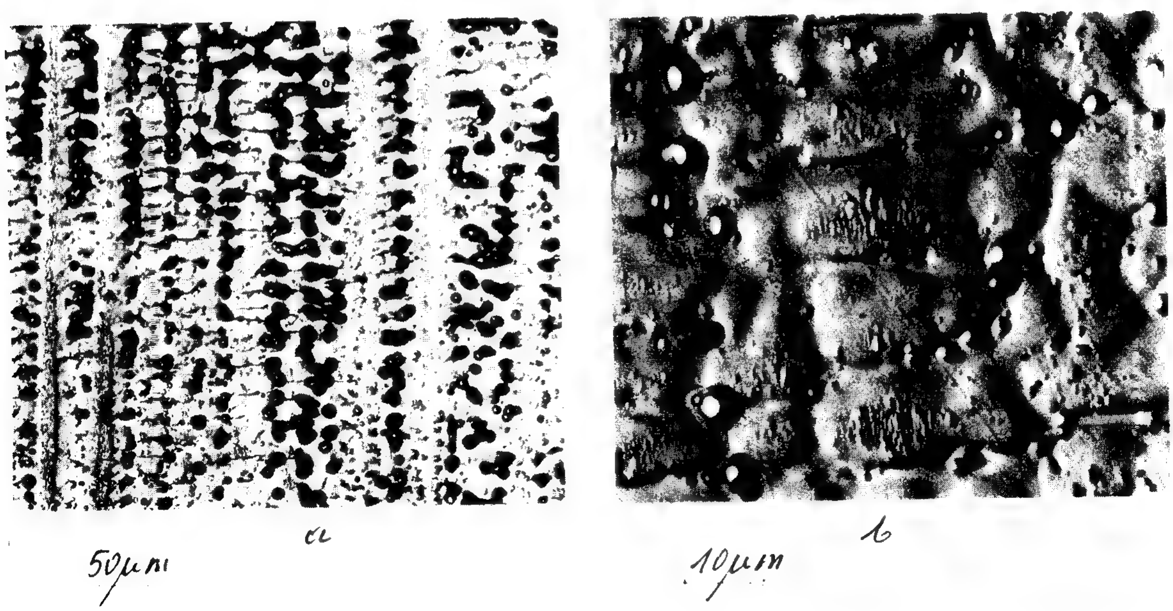


Fig.6. Structure of face layer
a/ structure: general view
b/ structure: enlarged fragment.
Etchant: 10% solution of oxalic acid.

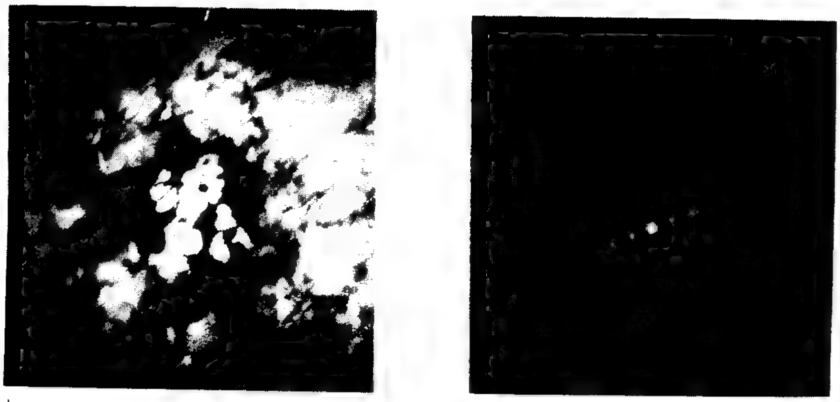


Fig.7. SWO7H25N13 filler metal - deposited first layer where phase precipitation was identified
a/structure; b/diffraction pattern of electrons /x50000/.

Fig.8. SWO7H25N13 filler metal - deposited first layer where $M_{23}C_6$ type carbide was identified
a/structure; b/diffraction pattern of electrons /x50000/.

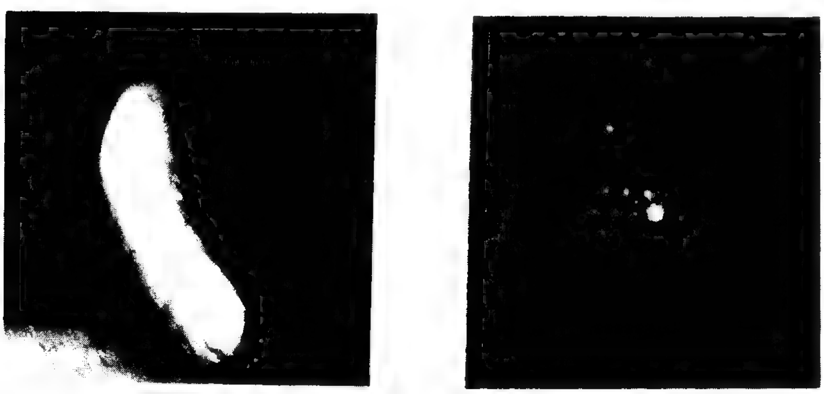


Fig.9. SWO8H19N10G2B filler metal -deposited second layer where phase precipitation was identified
a/structure; b/diffraction pattern of electrons /x50000/.

deposited cladding layer /see Fig. 2a/. Intermixing and diffusion processes occuring between the two cladding layers are also unimportant, but perceptible /Fig. 2b/. Large variations of alloying elements in the austenitic steel deposited by welding were observed, but no interpretation thereof will be given in this paper.

The content of high temperature δ-ferrite in the deposited metal was found to vary from 0.15 to 1.53%.

The deposited cladding layers exhibit a dendritic structure /see Fig. 3/, with the transition zones occuring between the layers as shown in Figs 4 and 5. Interpenetration of dendritic structures or the change in their growth direction can be observed.
The face layer of the cladding exhibits a dendritic structure with clearly visible spheroidal precipitations /see Figs. 6/ which can be of significant importance for the corrosion resistance of this layer.

As far as the weld-metal cladding properties are concerned an important role is attributed to the evaluation of heat treatment resulting from the weld depositing process. Within the framework of such on evaluation, test specimens in the form of thin metal foil were examined by using a transmission electron microscope. The electron diffraction method permitted to identify intermetallic σ-phase and $M_{23}C_6$ type carbides occuring in the I-st layer /Figs.7 and 8/ and σ-phase only in the II-nd layer. /Fig. 9/. On the basis of hither to available results of examinations one can state that the structure of the deposited layer corresponds to a heat treatment consisting of solution treatment and ageing.

6. MECHANICAL CHARACTERISTICS [6]

Strength properties of the weld-metal cladding were tested by using shear and tearing methods. From among large number of cladding tear tests the one as proposed by A.Bahrani and B.Crossland was adopted.
The results of tear tests conducted on cladding metal made with a strip electrode and by manual TIG method with addition of filler wire were within 506-513 MPa and 475-480 MPa, respectively.

The results of shear test indicated the strength varying from 532 to 607 MPa for strip made cladding and from 510 to 515 MPa for the cladding deposited by TIG - process.

The tests for cladding bonding conducted by shearing and tearing methods have indicated that the strength properties of two-layer cladding are comparable with a tensile strength of austenitic stainless steels /480-520 MPa/ which testifies to good strength characteristics of the cladding.

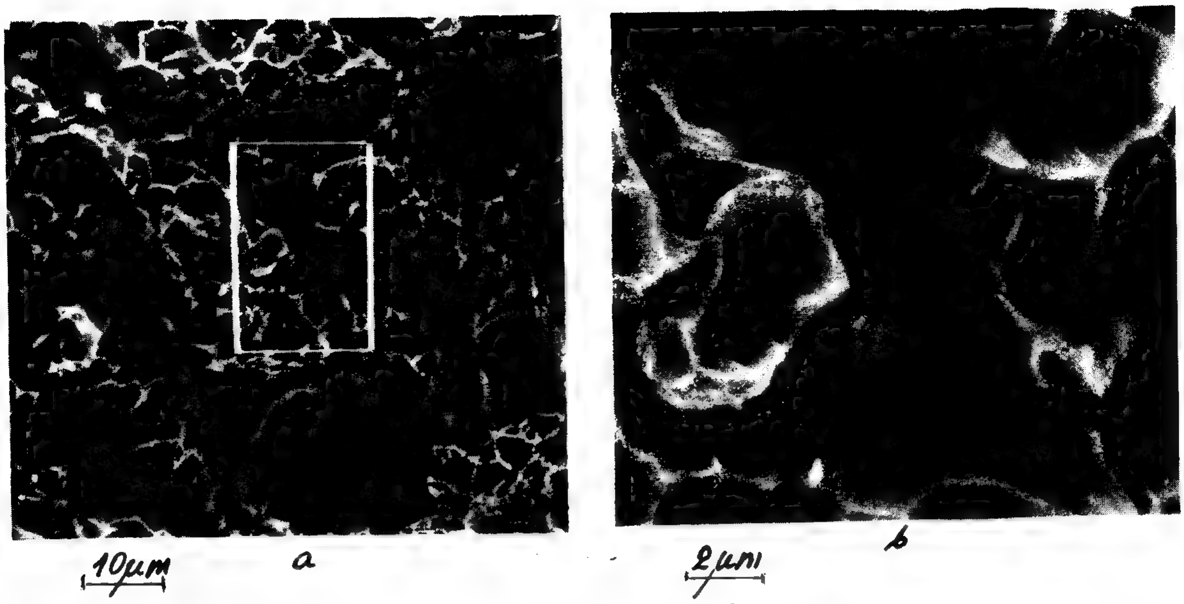


Fig.10. Topography of tear test-specimen fracture
a/ general view,
b/ enlarged fragment.

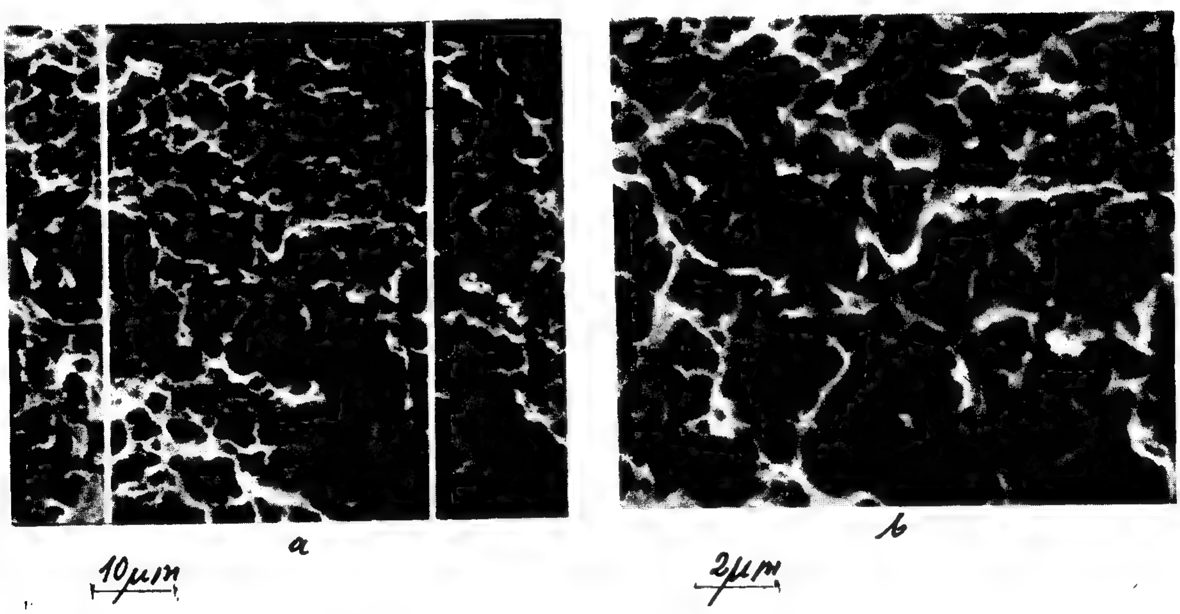


Fig.11. Topography of shear test-specimen fracture
a/ general view,
b/ enlarged fragment.

The satisfactory results of bond strength tests were verified by fractography examinations using a scanning electron microscope. The topography of the tear specimen after testing as presented in Fig.10 confirms a ductility of the fracture. Still better presentation of a ductile fracture has been obtained from shear tests /see.Fig.11a,b/.

The results of all tests and examinations provide a convincing evidence of the good quality of the cladding in question.

7. CONCLUSIONS

On the basis of the tests and examinations as conducted by the Authors the following conclusions can be formulated:

7.1. The obtainment of weld-metal cladding combining both the strength and corrosion resistance properties and free from welding defects such as cracks, undercuts and porosity requires a very careful control of welding parameters. Such a control is also of vital importance for maintaining a uniform transition zone at the parent metal cladding interface.

7.2. The cladding layer has a dendritic structure, the dendrite growth directions varying with those of heat abstraction. The dendritic structures of adjacent layers partly penetrate one another. The dendritic structure is not eliminated by stress-relieving treatment.

7.3. While the individual layers of cladding are being deposited the displacement of adjacent layer materials and diffusion processes occur on a limited scale only.

7.4. The thermal processes occuring in the course of welding were found to result in the precipitation of interstitial and intermetallic phases. While conducting their own investigations by using electron diffraction methods the Authors have identified the presence of σ-phase in both layers and the presence of $M_{23}C_6$-type carbides in the first layer.

7.5. The tests for cladding adherence quality conducted by shear and tear methods have yielded strength characteristics approximating those of the materials whose chemical composition would be that of the filler metal used.
The materials and technology as applied have made it possible to obtain a cladding whose quality satisfies all the requirements imposed on the production of PWR vessels.

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TABLE 1. Chemical compositions of certain low-alloy steel grades used in nuclear power engineering.

Type of steel	Content in weight %						
	C max	Mn	Si	Cr	Ni	Mo	V
24H2MF	0.20-0.30	0.5-0.80	0.17-0.37	2.1-2.5	-	0.9-1.2	0.3-0.6
15X2MA	0.13-0.18	0.70-0.60	0.17-0.37	2.5-3.0	0.4	0.6-0.8	0.25-0.35
897M39	0.35-0.43	0.45-0.7	0.1 -0.35	3.0-3.5	0.4 max	0.80-1.1	0.15-0.25
20CDV5.08	0.17-0.24	0.30-0.60	0.30-0.60	1.10-1.50	0.5	0.70-1.0	0.20-0.40
10H2M	0.80-0.15	0.4-0.60	0.15-0.5	2.0-2.5	0.30	0.9-1.1	-
A542-4	0.15	0.30-0.60	0.15-0.30	2.0-2.5	-	0.9-1.10	-
K22MA	0.10-0.18	0.80-1.10	0.17-0.37	0.30	0.30	0.25-0.40	-
22K	0.19-0.26	0.75-1.00	0.2-0.4	0.40	0.30	-	-

TABLE 2. Mechanical properties of low-alloy steel grades as per Table 1.

Type of steel	R_m min MPa	R_e MPa	A min %	%	HB
24H2MF	740	590	15	-	215-249HB
15X2HA	568-735	431	23	50	-
A543	724-862	586	14	-	-
877M39	850-1000	640	13	-	248-302HB
20CDV5.08	776-815	608	16	-	-
10H2M	440-590	265	20-1[illegible]	-	140-180HB
A542-4	586-723	413	-	-	-
10CD9.10	510-610	295	22	-	-
K22H	411-529	255	-	-	-
22K	431-588	226	-	45	-

TABLE 3. Chemical compositions of certain strips utilized in cladding

Type of steel		Standard	Content in weight						
			C	Mn	Si	Cr	Ni	Mo	Nb
308L	SFA5.9:ER308L	DIN8556: UPX2CrNi19.9	0.015	1.75	0.3	19.7	10		
316L	SFA5.9:ER316L	DIN8556: UPX2CrNiMo19.12	0.015	1.[illegible]	0.25	1[illegible].3	13.5	2.[illegible]	
347	SFA5.9:ER347	DIN8556: UPX5CrNiNb19.9	0.015	1.65	0.35	20.2	10		0.55
410L	SFA5.9 ER410	DIN8556: UP X8Cr14	0.020	0.6	0.3	13			
	SWO7H25HB	GOST	0.06	1.39	0.[illegible]2	24	13		
	SWO8H19N101G2B	GOST	0.06	1.90	0.20	19	10		1.1

EXPERIMENTAL INVESTIGATION OF NEUTRON FLUX IN HORIZONTAL REACTOR CHANNELS BY NEUTRON DIFFRACTION METHOD

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ABSTRACT

The measurements of thermal neutron spectra were carried out in horizontal experimental channels No. 7, 9 by neutron diffraction method. The data obtained showed different results, which indicate the heterogenity of the core reflector. For precise determination of maximum spectrum new approach has been suggested, which accounts for the influence of multiple harmonic of scattering wavelength and multiscattering process in crystal. Maxwell approximation was used for calculation "neutron gas" parameters in core reflector.

1. INTRODUCTION

Reactor core bryllium reflector is the source of thermal neutrons for solid state physics research. It is known that the high energy neutrons are formed as a result of nuclear fission reaction and loss of their energy coupled with moderator nuclei. These neutrons aspire to reach gradually the state of thermal equilibrium with moderator. However, thermal equilibrium is never reached in practice due to the neutron capture by the moderator nuclei and the neutron leak from the moderator. Therefore the neutron spectrum in the moderator appears to be harder than the Maxwellian equilibrium distribution.

The knowledge of the thermal neutron energy distribution is necessary to optimize crystalline structure research by diffraction method. Determination of effective neutron temperature and moderator equilibrium temperature is important for nuclear reactor maintenance.

2. PROCEDURE

The distribution of thermal neutrons in a reactor moderator may be expressed as Maxwellian [1]

$$\delta n_1 = K_1 v^2 exp\{-v^2/v_0^2\}\delta v, \qquad (1)$$

where: δn_1- is the number of neutrons in a velocity interval Δv about v;
v_o- is the most probable neutron velocity; K_1 = Const.

The number of neutrons extracted from reactor moderator through horizontal reactor channel will be

$$\delta n = v \delta n_1 = K_1 v^3 exp\{-v^2/v_o^2\} \delta v, \qquad (2)$$

express the neutron spectrum in reactor channel in the variables of wavelength.

$$\delta n = K_2 (\delta \lambda / \lambda^5) exp\{-\lambda_o^2/\lambda^2\} \delta \lambda, \qquad (3)$$

taking into account that $\lambda = h/mv = 3.96/v = 0.286\sqrt{E}$ and $\lambda_o = h/mv_o$.
where the units of measurements are: velocity - km/sec, energy - eV.

Generally we can prepare neutron spectra in channel as neutron intensity count versus: scattering angle -2θ wavelength $-\lambda$ neutron velocity $- v$, neutron energy - E, or neutron temperature - T, by measurement intensity of the monochromatic scattering neutrons for diffractometer and spectrometer. The fission chamber RM-20 is used as "black" neutron detector with efficiency represents to 10^{-3}.

Let us discuss the problems of crystalline monochromator response. The reflection intensity of large flat single crystal in "white" neutron spectrum and crystal reflection possibility are determined [2].

$$I = I_o K_3 Q\, exp\{-\mu t \sec\theta\} exp\{-2W\} E'/\sin 2\theta \qquad (4)$$

$$Q = \lambda^4 F^2 / 2V \sin 2\theta, \qquad (5)$$

where: $I_o = \delta n / \delta \lambda$ - is the neutron flux in reactor channel, μ - linear absorption coefficient, t - crystal thickness, $exp\{-2W\}$- Debye factor, E' - secondary extension coefficient, θ - angle of scattering: F^2 - structural factor, V - crystal volume.

According to Bragg Law $2 d_{hkl} \sin\theta_{hkl} = n\lambda$, in cases of "white" spectrum of incident neutrons the monochromator produces multiple harmonic for the same scattering angle. Intensities of these harmonic are strongly dependent on reflection capability (see equations 4, 5). The contribution of high order reflection can be taken into consideration by additional analysis of the monochromatic beam with the help of the single crystal sample. In this case the neutrons of multiple λ will be scattered to different angles by the sample lattice (see more deep description in [3]. For incident monochromatic beam the equation (4, 5) will transform [2].

$$I = I_o Q_M exp\{-\mu t \sec\theta\} exp\{-2W\} E'/\sin 2\theta \qquad (6)$$

$$Q_M = \lambda^3 F^2 / V \sin\theta \qquad (7)$$

where I_o - is the monochromatic neutron intensity of λ wavelength.

3. EXPERIMENTAL DATA AND DISCUSSION

Obtained spectra results for thermal neutrons diffracted by plane (III) of copper monochromators for channels 7 and 9 are given accordingly in figs. 1 and 2. Large fluctuations of the count rate (versus) the wavelength are observed in those figures. This cannot be explained by statistical spread since the mean-square-root statistical effor does not exceed the dimensions of experimental points on the graphs. These intensity fluctuations are explained by the multiscattering process inside the monochromator crystalline lattice, and may be taken into account experimentally with high accuracy. It is necessary to rotate the crystal around the scattering vector for this purpose. At such rotation other points of crystal reciprocal lattice which stipulate multiscattering process will be out of Ewald sphere and the intensity of reflected neutrons will change.

Effective maxima of experimentally observed intensities for channel No. 7 are $\lambda_{ef} = 1.30\cdot10^{-10}m$ (or $v_{ef} = 3046\,m/sec;\ E_{ef} = 0.0484\,eV$) and for channel No. 9 $\lambda_{ef} = 1.38\cdot10^{-10}m$ ($v_{ef} = 2870\,m/sec;\ E_{ef} = 0.0430\,eV$). However, as it was mentioned in previous section within wavelengths greater than $1\cdot10^{-10}m$ multiple harmonics of wavelength introduce essential contribution in the observed intensity. Therefore, the observed maximum does not correspond to correct parameter value of the neutron flux.

In order to take into account the high harmonic contributions we use the experimental results of ref [3] for intensity of (220) peaks of Fe-Ni single crystal specimen by different wavelengths. The details of procedure of extraction for multiple harmonic are given in ref [4]. Curve 1 of fig. 1 represents the spectrum without high order contributions. Real maxima of spectra for channel No. 7 are $\lambda_{max} = 1.2\cdot10^{-10}m$ ($v_{max} = 3300\,m/sec;$ $E_{max} = 0.0568\,eV$)
and for channel No. 9 $\lambda_{max} = 1.33\cdot10^{-10}m$ ($v_{max} = 2377\,m/sec;$ $E_{max} = 0.0462\,eV$).

The comparison of spectra in figs. 1, 2 gives a very important physical result: the maxima of neutron spectrum distributions for channels No.7 and No. 9 are different. Hence, the neutron reflector of reactor, which is the neutron source for horizontal channels is heterogeneous.

4. CALCULATION OF EQUILIBRIUM PARAMETERS OF NEUTRON FLUX AND MODERATOR OF REACTOR

The most probable flux is at the speed:

$$v_{max} = \sqrt{3/2}\, v_0 \quad , \quad v_0 = v_{max}/1.225 \tag{8}$$

by differentiation of equation (2) and setting the derivative equal to zero. For further calculations, expression (2) will be used in the form: $\delta n/\delta\theta = K\cos\theta\, v^3 \exp\{-v^2/v_0^2\}$ to determine the constant K from the count intensity of neutron scattered an angle θ_{max} with velocity v_{max}.

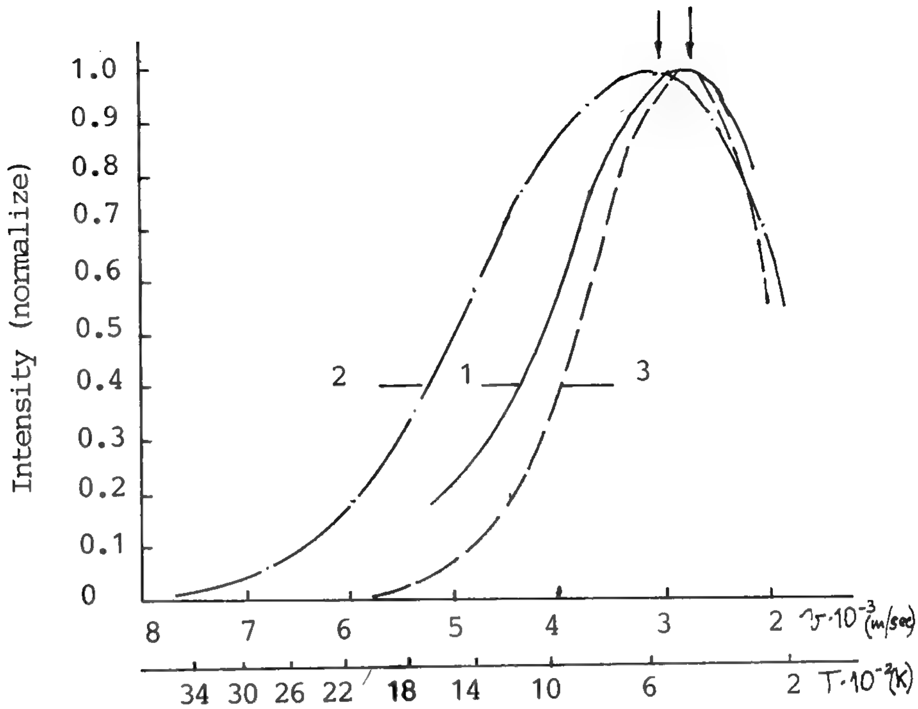

Fig. 1 : Spectra for Channel No.7

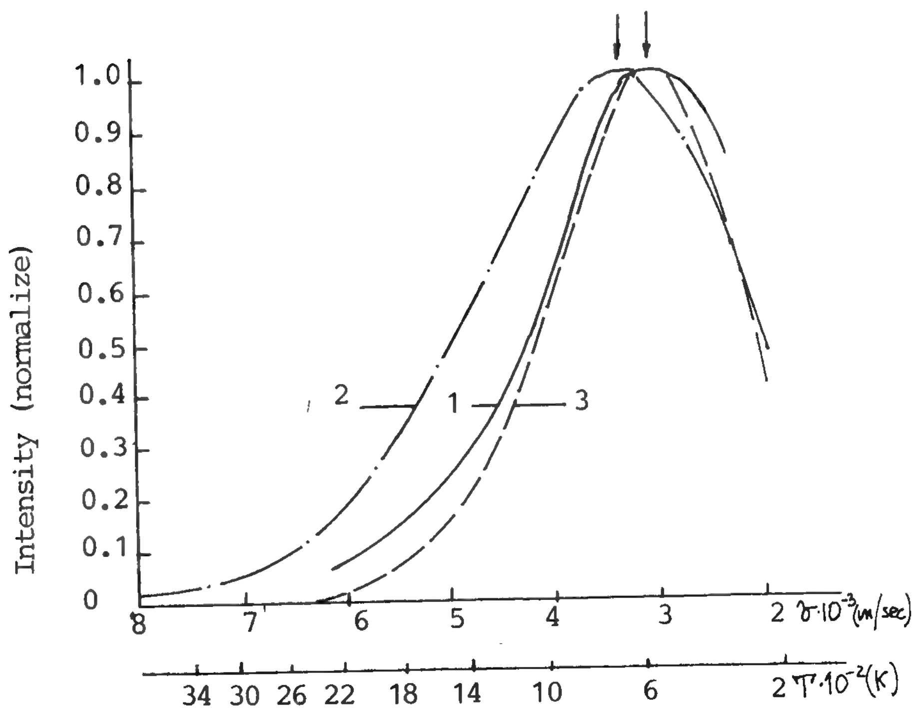

Fig. 2 : Spectra for Channel No. 9

——— - Experimental Neutron Spectrum
- - - - - Calculated Spectrum for Channel
-·-·- - Calculated Spectrum for Moderator

Table 1 : Characteristic Parameters of Neutron Distributions in Channels and Moderator of RWW-7 Reactor

	Experiment				Maxwellian Approximation				Equilibrium Parameters				
Parameter / Channel	λ (Å)	E (eV)	v (m/sec)	T_{flux} (K)	λ (Å)	E (eV)	v (m/sec)	T_{flux} (K)	λ (Å)	E (eV)	v (m/sec)	T_{flux} (K)	T_{mod} (K)
HEC-7	1.300	0.0484	3046	751	1.200	0.0568	3300	881	1.470	0.0379	2694	587	440
HEC-9	1.380	0.0430	2870	666	1.330	0.0462	2977	717	1.630	0.0287	2342	444	333

Normalized results of the neutron flux distribution in horizontal reactor channels No. 7, 9 by usage of expression (2) and neutron distribution in reactor reflector expression (1) are given in figs. 1, 2 accordingly. Allow to compare theoretically the calculated neutron distribution in reactor and in reactor channel with those reflected from monochromator crystal.

The temperature of neutrons is related to their average kinetic energy by the formula:

$$1/2\, m v^2 = 3/2\, kT, \qquad (9)$$

where m - is the neutron mass, k - is the Boltzman's constant. For determination of the mean-square-root velocity of neutrons in the flux and in the moderator the following expressions are suggested:

$$\overline{v^2_{flux}} = \int v^2 d(nv) \Big/ \int d(nv) = 2 v_0^2 \qquad (10)$$

$$\overline{v^2_{mod}} = \int v^2 dn \Big/ \int dn = 3/2\, v_0^2 \qquad (11)$$

Hence, equilibrium neutron temperatures in reactor channels and moderator are determined by the expressions:

$$T_{flux} = 2 m v_0^2 / 3k \qquad (12)$$

$$T_{mod} = m v_0^2 / 2k \qquad (13)$$

Neutron parameters in reactor channel and moderator are given for comparison in table 1.

5. CONCLUSION

Analysis of the intensity of neutron manochromatic incident beam versus wavelength are carried out for choosing the optimal conditions of diffraction investigations for many problems of Solid State Physics.

The modified procedure of analysis was used for more precise determination of the equilibrium parameters of the neutron beam in channel and the "neutron gas" inside moderator of reactor. This modification allows to take into account the effects of multiple harmonic of wavelength and multiscattering processes inside crystalline monochromator for correct determination of the maximum of neutron spectrum. As a result of this it was determined, that the neutron spectrum in horizontal channel No. 7 possesses harder than that of channel No. 9 i.e. the sections of reactor moderator which correspond to different horizontal channels are heterogeneous.

The obtained neutron flux parameters and moderator temperatures may be compared with results of research at critical stand and reactor. They may be used also to calculate the physical processes in nuclear reactor.

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Two-Dimensional, Two-Regions Reflooding Analysis Following LOCA in LWR^s

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Abstract :

This paper presents a two-dimensional analysis for the rewetting process, following Loss-Of-Coolant Accident (LOCA) in light water reactors (LWR'S). The fuel rod is divided into two regions,wet region behind the rewetting front,and dry region infornt of the rewetting front. The rewetting front progress with velocity depending on the mechanism of heat transfer and the initial wall temperature. The heat conduction equation is solved analytically for the temperature distribution in both the wet and dry regions as a series solution. The coeffecients of the analytical solution are determined numerically by considering N-nodes equally spaced along the radial axis in cladding thickness at the interface between the wet and dry regions, by applying the contimuity of temperature and axial heat flux at different nodes. Using computer program we obtain the temperature distribution, reflooding velocity and axial and radial heat flux in the cladding.

The reflooding velocity was found to decrease with initial surface temperature and the value of decay heat generation, and increase with Biot number. The cladding surface temperature in the wet region reach the saturation temperature in a very short distance from the wet front due to the high heat flux in this region. Also, the constant heat flux lines indicates that the reflooding phenominon is local and controlled by a very small heat flux zone surrounding the wet front.

1- Introduction :

Loss-Of- Coolant Accident (LOCA) is considered a design base accident DBA for Light Water Reactor (LWR's) in case of complete shear in the cold leg for Pressurized Water Reactor (PWR) or in the inlet of the circulating loop in Boiling Water Reactor (BWR).

An emergency core cooling system (ECCS) is provided to prevent metal water reaction that may occur at high temperature of Zirconium cladding leading to fuel fracture and release of radioactivity and core meltdown.

LOCA in LWR's is characterised by three periods, Blow down period which continue for 13 to 20 seconds in case of large break LOCA, then the core will be dry. Then the refill period starts with the operation of the ECCS. Rewetting of the dry core starts when the water level reaches the bottom of the fuel rods. As the cooling water comes in contact with hot cladding surface, violent film boiling occures at the leading edge progressing the wet front over the cladding surface.

The velocity of the rewetting front is important in evaluating the performance of the ECCS. After blow down period the core became dry with very low heat transfer from the surface. Redistribution of the fuel temperature occurs (due to the high temperature gradient inside the fuel rod) within few seconds and the fuel temperature can be considered uniform according to experimental observations and theoritical analysis. [1 - 3]. The solution of the rewetting process is made by number of theoretical models using; one dimensional analytical analysis as [4,5], two-dimensional analytical analysis [6] and two - dimensional numerical solution as [7]

In our work we obtain the velocity of the rewetting front by solving the two - dimensional transient heat conduction equation in the cladding in two separate regions ahead and behind the reflooding front using computer program. The temperature distribution and temperature gradient are also calculated for the hollow cylinderical cladding of the fuel rod.

2- Theory :

A proper representation of the rewetting process is made by using a two dimensional, two regions semi-analytical model with decay heat generation. The fuel rod is divided into two regions, according to the mechanism of heat transfer, wet region behind the rewetting front with average boiling heat transfer coefficient h_w, and dry region infront of the rewetting front with average dry heat transfer coefficent h_d , as shown in fig.(1).

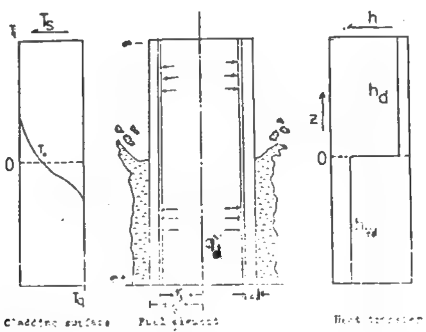

Fig.(1) : Two - regions model for hollow cylinderical cladding.

The fuel rod is considered to be infinitly extended with a cladding thickness S The cladding surface is assumed to have uniform initial temperature T_i , which is greater than the min.film boiling temperature (the sputtering temperature) T_o , decay heat is produced in fuel with a uniform heat generation source q_d'''.

The two dimensional fourier heat conduction equation for the cladding is given by

$$\frac{1}{r} \cdot \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) + \frac{\partial^2 T}{\partial z^2} = \frac{\rho C}{K} \frac{\partial T}{\partial t} \quad \text{.........(1)}$$

This equation can be simplified by taking a new coordinate system in which the origin moves along with the wet front, using Gallilian transformation , $\mathcal{Z} = z - vt$. Using dimensionless parameters ;

$$R = \frac{r}{\delta} \quad , \quad Z = \frac{\mathcal{Z}}{\delta} \quad , \quad \theta = \frac{T - T_{sat}}{T_o - T_{sat}} \quad , \quad B_w = \frac{h_w \delta}{K}$$

$$B_d = \frac{h_d \delta}{K} \quad , \quad \theta_q = \frac{q_d''' \; r_i^2 \; \delta}{2 \, r_o \, h_w \, (T_o - T_{sat})} \quad ,$$

The fourier equation new take the form

$$\frac{\partial^2 \theta}{\partial Z^2} + P \frac{\partial \theta}{\partial Z} + \frac{\partial^2 \theta}{\partial R^2} + \frac{1}{R} \quad \frac{\partial \theta}{\partial R} = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Using seperation of variables technique the general solution of the diff.eq. is given by,

$$\theta(R,Z) = \sum_{i=1}^{\infty} (C_{1i} \, e^{m_{1i} z} + C_{2i} \, e^{m_{2i} z}) (C_{3i} J_o(\mu_i R) + C_{4i} Y_o(\mu_i R)) +$$

$$C + B \ln R + F_e^{-PZ} + E \ln R \, e^{-PZ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where,

$$m_{1i} = -\frac{P}{2} + \left(\frac{P^2}{4} + \mu_i^2\right)^{\frac{1}{2}}$$

$$, \; m_{2i} = -\frac{P}{2} - \left(\frac{P^2}{4} + \mu_i^2\right)^{\frac{1}{2}}$$

μ_i is the seperation constant.

The wet region and the dry region are considered seperately with the proper boundary conditions.

For the wet region I $(Z < 0)$; the boundary conditions are

$$\theta_I (R, -\infty) = \theta_q + \frac{q_d''' \; R_i^2 \; \delta}{2R_o \, h_w \, (T_o - T_{sat})} \; \ln \left(\frac{R_o}{R}\right) , \ldots\ldots\ldots \quad (4)$$

$$\theta_I (R_o , 0) = 1 \quad , \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$\left.\frac{\partial \theta_I}{\partial R}\right|_{R_i} = - \frac{q_d''' \; R_i' \; \delta^2}{2 K \, (T_o - T_{sat})} \quad , \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$- \frac{1}{B_w} \left.\frac{\partial \theta_I}{\partial R}\right|_{R_o} = \theta_I \Big|_{R_o} \quad , \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

By applying the boundary conditions to equation (3), the temperature distribution in the wet region is given by,

$$\theta_I(R,Z) = \sum_{i=1}^{\infty} C_{Ii}\, e^{m_{1i_I} Z} \left(J_o(\mu_{i_I} R) - \frac{J_1(\mu_{i_I} R_i)}{Y_1(\mu_{i_I} R_i)} Y_o(\mu_{i_I} R) \right)$$

$$+ \theta_q + \frac{q_d''' \, R_i^2 \, \delta^2}{2K\,(T_o - T_{sat})} \ln \left(\frac{R_o}{R}\right) \quad \ldots\ldots\ldots\ldots\ldots(8)$$

The seperation constants (μ_i) can be obtained by using equ. (7), and the result is a transidental equations of the form,

$$B_w = \mu_{i_I} \frac{J_1(\mu_{i_I} R_o)\; Y_1(\mu_{i_I} R_i) - Y_1(\mu_{i_I} R_o)\; J_1(\mu_{i_I} R_i)}{J_o(\mu_{i_I} R_o)\; Y_1(\mu_{i_I} R_i) - Y_o(\mu_{i_I} R_o)\; J_1(\mu_{i_I} R_i)} \quad \ldots\ldots\ldots\ldots (9)$$

$, i = 1, 2, \ldots\ldots\ldots\ldots, \infty$

For the dry region II ($Z > 0$) ; the boundary conditions are,

$$\theta_{II}(R, \infty) = \theta_i + \frac{q_d''' \, R_i^2 \, \delta^2}{2K\,(T_o - T_{sat})} \ln \left(\frac{R_o}{R}\right), \quad \ldots\ldots\ldots(10)$$

$$\theta_{II}(R_o, 0) = \theta_o = 1, \quad \ldots\ldots\ldots\ldots(11)$$

$$\left.\frac{\partial \theta_{II}}{\partial R}\right|_{R_i} = \frac{-q_d''' \, R_i \, \delta^2}{2K_c\,(T_o - T_{sat})}, \quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

$$-\frac{1}{B_d} \left.\frac{\partial \theta_{II}}{\partial R}\right|_{R_o} = \theta_{II}\Big|_{R_o}, \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

Applying boundary conditions in equation (3), the temperature distribution in the dry region is given by,

$$\theta_{II}(R,Z) = \sum_{i=1}^{\infty} C_{II\,i}\, e^{m_{2i_{II}} Z} \left(J_o(\mu_{i_{II}} R) - \frac{J_1(\mu_{i_{II}} R_i)}{Y_1(\mu_{i_{II}} R_i)} Y_o(\mu_{i_{II}} R) \right)$$

$$+ \theta_i + \frac{q_d''' \, R_i^2 \, \delta^2}{2K\,(T_o - T_{sat})} \cdot \ln \left(\frac{R_o}{R}\right) \quad \ldots\ldots\ldots\ldots\ldots (14)$$

The seperation constant in this region can be obtained from the transidental equation,

$$B_d = \mu_{i_{II}} \frac{J_1(\mu_{i_{II}} R_o)\; Y_1(\mu_{i_{II}} R_i) - Y_1(\mu_{i_{II}} R_o)\; J_1(\mu_{i_{II}} R_i)}{J_o(\mu_{i_{II}} R_o)\; Y_1(\mu_{i_{II}} R_i) - Y_o(\mu_{i_{II}} R_o)\; J_1(\mu_{i_{II}} R_i)} \quad \ldots(15)$$

$, i = 1,2 \ldots\ldots\ldots, \infty$

3- **Numerical analysis :-**

In this model N terms of the series solution of the temperature distribution in the wet and dry regions are considered with the coefficients being determined numerically by considering N different nodes at the interface between the two regions.

Starting from analytical solution of the temperature distribution in the wet region and dry region given by :

$$\theta_I = \theta_{qI} + B_i \theta_{qI} \ln \left(\frac{R_o}{R}\right) + \sum_{i=1}^{N} C_{1i} \; e^{m_{1i_I} z} \left(J_o(\mu_{i_I} R) - \frac{J_1(\mu_{i_I} R_i)}{Y_1(\mu_{i_I} R_i)} Y_o(\mu_{i_I} R)\right) \quad \ldots\ldots (16)$$

$$\theta_{II} = \theta_i + B_d \theta_i \ln \left(\frac{R_o}{R}\right) + \sum_{i=1}^{N} C_{2i} \; e^{m_{2i_{II}} Z} \left(J_o(\mu_{i_{II}} R) - \frac{J_1(\mu_{i_{II}} R_i)}{Y_1(\mu_{i_{II}} R_i)} Y_o(\mu_{i_{II}} R)\right) \quad \ldots\ldots (17)$$

To evulnate the constants C_{1i}'s , C_{2i}'s and the dimensionless rewetting velocity P, we are need of (2N + 1) equations. Applying continuity of temperature and axial heat flux at the N nodes. We obtain the linear system of 2N equations.

The computer program SARA II (semi-analytical rewetting analysis) is written to obtain the 2N coefficients (C_{1i} , C_{2i}) for the temperature distribution in the two regions, and rewetting velocity. Axial and radial heat flux in cladding are also obtained.

The method of solution involves an iteration loop on P. The value of P used as a first guess is obtained from the approximate one dimensional solution [3], the 2N linear algebric equations are solved to obtain the coefficients. The coefficients are used to calculate the surface temperature at the wet front (θ_o). The calculated θ_o must be equal to unity for the solution to be accurate. If $|\Delta\theta_o| \doteq |\theta_o - 1|$, is less than an accuracy (ACC), Acc is taken 0,001 the interation is considered to be converged and the value of P used in this interation gives the correct rewetting velocity for the value of N used. If $|\Delta\theta_o| >$ Acc, we repeat the iteration by adding or subtracting an increment ΔP to the proceeding value of P. For positive $\Delta\theta_o$ we subtract ΔP from the previous one, because increasing the sputtering temperature gives a value of P greater than the actual one, and vice versa.

Upon convergence of iteration we check the continuity of the temperature at intermediate points between the nodes used. The difference between temperature obtained from the boiling and dry regions, $\Delta\theta$, is found to have its maximum value $\Delta\theta_{max}$ at the first intermediate position, where the maximum temperature gradient occures. This difference is

used as a measure of the proper value of N. If $\left|\frac{\Delta \theta_{max}}{\theta}\right|$ is less than or equal to ACC, then the value of N is the proper one.

If $\left|\frac{\theta_{max}}{\theta}\right| > ACC$, then N should be increased and the iteration is repeated. The value of N was found to increase with B_w.

Also, the axial and radial temperature distribution in the wet and dry region $\theta_I(R,Z)$ and $\theta_{II}(R,Z)$ and the axial heat flux are calculated, Using the value of C_{1i} and C_{2i} obtained.

4- Analysis of the results :-

The results of the computer program show that, the rewetting velocity decreases with the initial surface temperature T_i for the same value of Biot number B_w, as shown in Fig. (2),

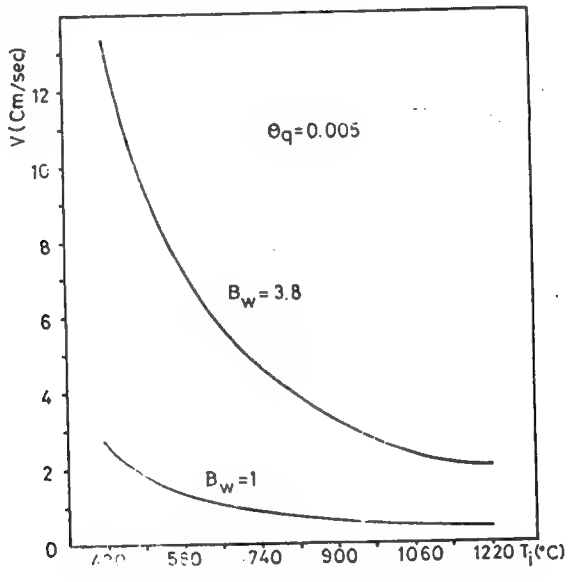

Fig.(2) Variation of rewetting velocity with initial temperature.

The rewetting velocity is more sensitive to the changes in initial surface temperature for smaller values of T_i. The figure also shows that for the same T_i, the rewetting velocity increases with boiling Biot number B_w, due to the increase in heat removal in the wet side.

The variation of the rewetting velocity with T_i for different decay heat generation rates (θ_q) as shown in Fig.(3). The figures show that for the same T_i, the rewetting velocity decreases with increasing θ_q, and the effect is very small.

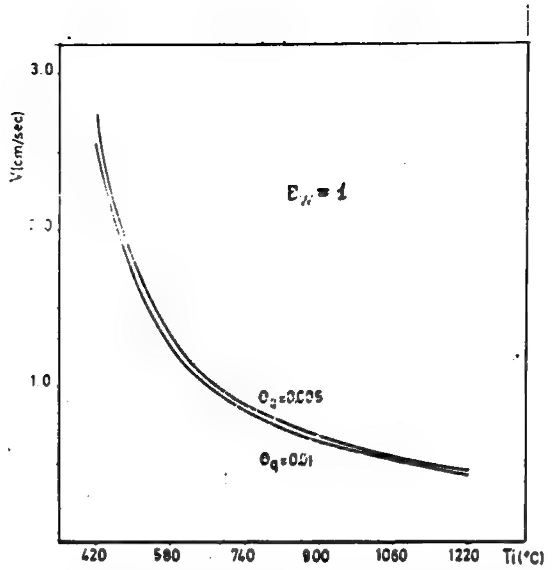

Fig.(3):Variation of velocity with initial surface temp. for different values of decay heat generation

The axial temperature distribution for B_w = 5and T_i=1220°c is shown Fig.(4) The surface temperature at the wet front is the sputting temperature (which is equal to 260°c for water at atmospheric pressure). In the wet region the surface temperature drop, sharply to the saturation temperature after very short distance of about 0.3 cm. and the inner cladding temperature is about 1200°c at Z = 0 and reaches the saturation temperature after about 0.6 cm. In the dry region the temperature changes on the inner surface from T_i 1220°c to 1200 at about 0.23 cm, While changes in the outer surface from 1220°c to the sputting temperature in the same distance. This indicates that the rewetting phenoninon took place in a very short distance surrounding the wet front compared to the fuel rod length of 12ft (365 cm) which is considered infinity extended.

The radial temperature distribution in the cladding at the wet front is given in Fig. (5). B_w = 1 and 3.8. The temperature gradient for B_w = 3.8 is higher than that for B_w = 1 due to the high heat extracted from the surface for higher Biot Number in the wet region B_w.

Constant temperature lines (isotherms) inside the cladding for B_w = 5 and initial cladding temperature of 1220°c are shown in Fig.(6).

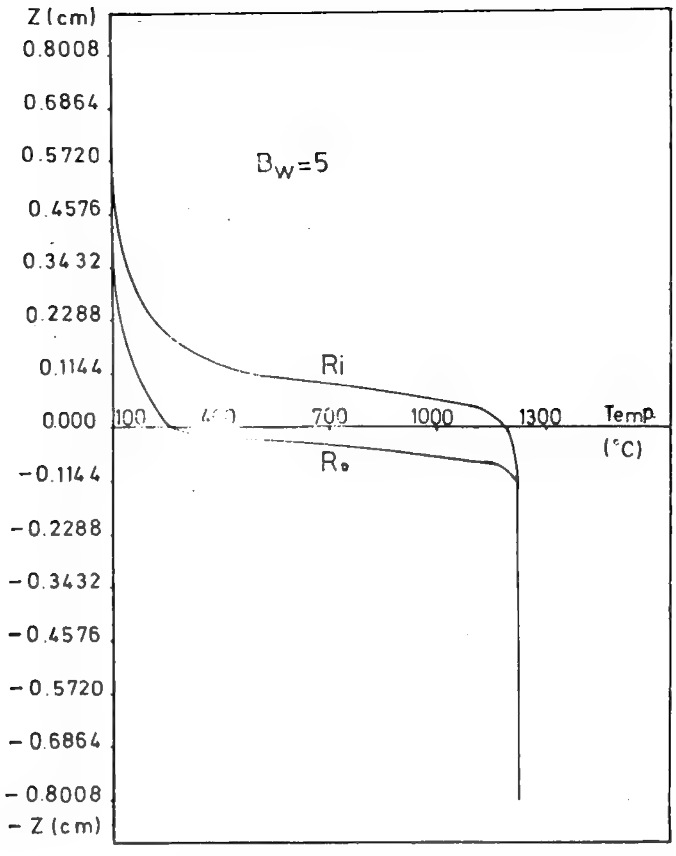

Fig.(4):Axial temp. distribution at inner &outer surface of the cladding

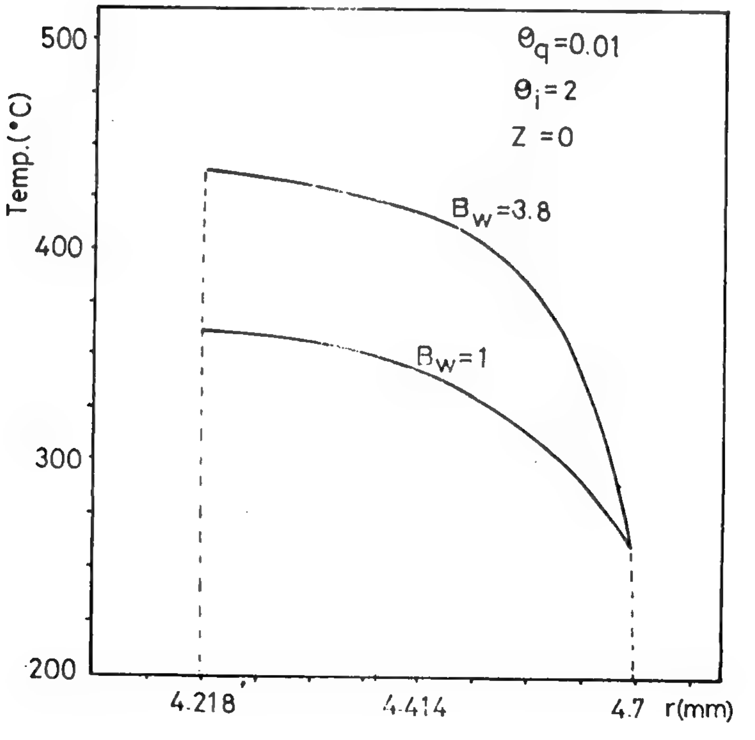

Fig. (5) Radial temperature distribution for different Biot number at Z = 0.0.

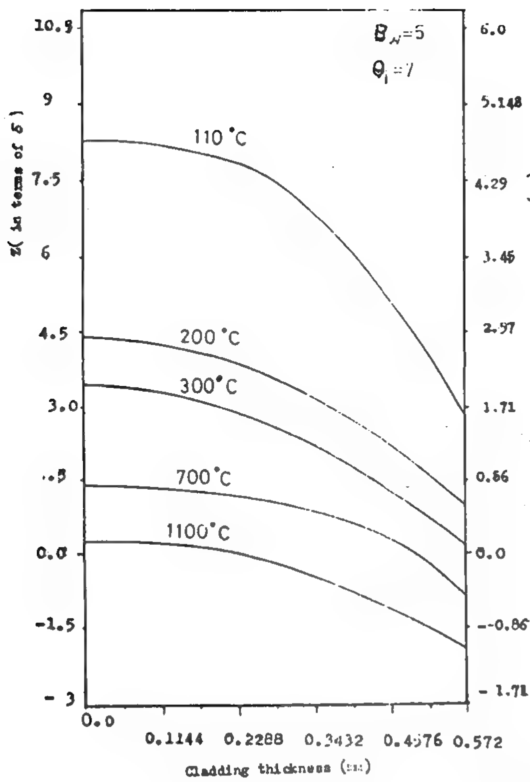

Fig.(6) Constant Temperature Lines Inside The Cladding.

The figure show that the temperature difference between the inner and outer surface is high in the wet region due to the high heat transfer from the surface and is higher near the wet front. The constant temperature lines are closer in the dry region with higher axial temperature gradient.

We can now explain the heat transfer mechanism in the rewetting process as axial conduction of heat in the wet and dry regions with high radial conduction in the wet region specially near the wet front (due to high heat transfer coefficient in the wet region). The radial heat conduction in the dry region is very small (with small dry region heat transfer coefficent). Fig. (7) show the constant axial heat flux temp.gradient lines with the wet front surrounded by high heat flux zone. The axial heat flux decreases to 1% of its value at the wet front within 0.15cm. in the wet cladding surface.

Finally, We can conclude that the rewetting phenominon is a local phenomina controlled by a very small high heat flux zone surrounding the wet front. The front velocity decreases with the initial surface temperature and decay heat generation and increases with the heat transfer coefficient in the wet region (Emergency cooling flow rate).

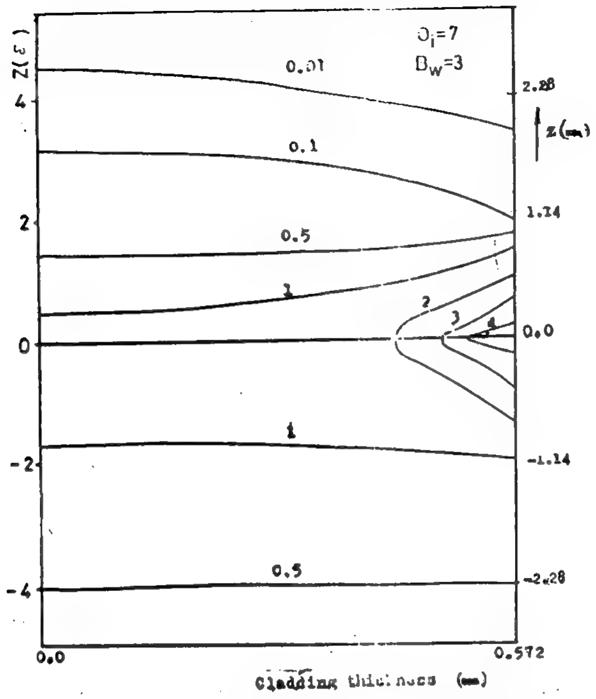

Fig. (7) Constant axial temperature gradient lines within the cladding.

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Study of the performance of the Emergency Core Cooling System (ECCS). Using One - Dimensional Four Region Model.

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ABSTRACT

In this work we study the performance of the (PWR), Emergency Core Cooling System (ECCS) following the Loss-of-coolant accident (LOCA). One dimensional analytical model, in four regions (non boiling 'boiling' fog and dry) according to the heat transfer mechanism on the cladding surface is used to show the effect of operating parameters on the rewetting velocity boiling and fog zones. The rewetting velocity is found to increase with Biot number Bb and decrease with initial cladding surface temperature Θ_i and heat generation Θ_q , the effect of Θ_q is very small. The boiling length is found to decrease with Biot number Bb and initial cladding surface temperature Θ_i and increase with the heat generation Θ_q, The fog length is found to decrease with Biot number Bb and increase with initial cladding surface temperature. The rewetting velocity is is compared with the more accurate two dimensional models.

INTRODUCTION

Following large break, LOCA, in water reactors, the core became dry in a very short blowdown period. The dry cladding surface temperature increases sharply due to stored heat and continous generation of decay heat inside the fuel. The operation of the, ECCS, refill the pressure vessel. The water can not rewet the hot cladding surface unless the surface temperature decreases to the minimum film boiling temperature (which is called the sputtering temperature for vertical surface). The rewetting front moves upward due to, axial conduction from the hot upper part to the lower dry part and precursory cooling with droplets ahead the wet front.

A number of theoritical models are proposed for the analysis of the rewetting process. Yamanouchi [1] was the first one to give the one dimensional solution for the infinitly extended slab neglecting heat generation and considering the rewetting velocity constant alover the

slab using two-regions, boiling and dry. A .F. El-Saidi, et.al., introduce two one-dimensional models, two - regions model (boiling and dry) and three-regions model (non boiling, boiling and dry) for hollow cylinderical cladding with decay heat generation inside the fuel [2].

The effect of procursory cooling was introduced in one-dimensional analysis by Sun, Dix and Tien [3] and Chun and Chon [4]. A number of two - dimensional analytical and numerical model are given in the literature [5 - 8].

In the present work we will give a simple and more exact representation for the heat transfer coefficient alover the hollow cylinderical cladding surface by using four regions model, with the wet region behind the wet front divided into boiling region with average boiling heat transfer coefficient, h_b, and nonboiling region with forced convection heat transfer coefficient h_c and ahead of the wet front a fog region cooled by sputtered droplets with average fog heat transfer coefficient h_f and dry region cooled by steam with average dry heat transfer coefficient h_d. Decay heat generation in the fuel is considered in the model.

2. Theoretical Model :

We consider a fuel rod with radius (r_i) surrounded by hollow cylinderical cladding with outer radius ' r_o ' with thickness δ . The volumetric decay heat source inside the fuel is q'''. The cladding surface initially at temperature ' T_i ' is cooled by bottom flooding of subcooled water.

After a transient period at the lower end of the core the liquid film progress upward the outer surface with constant front velocity. A simple one - dimensional head balance for cladding elements gives :-

$$q_z - q_{z+\Delta z} + q''' \Delta v_f - q_c = \rho c \Delta v_c \frac{dT}{dt} \quad \text{...........} \quad (1)$$

where,

q = heat rate,

q_c = heat transfer by convection,

ρ = density of cladding,

c = specific heat of cladding,

Δv_f = fuel demand of volume,

Δv_c = cladding element of volume.

Assuming a constant rewetting velocity v , we take the orgin of coordinating moving with the wet front, $Z = z - v t$, to eleminate the time from equ. (1), we get

$$\frac{d^2\theta}{dZ^2} + P \frac{d\theta}{dZ} - B.H^{\#} (\theta - \theta_{sub}) = - B.H^{\#} \theta_q \quad \text{.........} \quad (2)$$

where, θ, P, Z, B, θ_q are dimensional groups given by :

$$\theta = \left(\frac{T - T_{sat}}{T_o - T_{sat}} \right) , \qquad Z = \frac{z}{\delta}$$

$$P = \text{rewetting velocity} = \frac{\rho c \delta v}{k}$$

$R^{\#}$ = radial coordinate

$$R^{\#} = 2 * (R_1 + 1)(2R_1 + 1) ,$$

$$R_1 = \frac{2 r_o}{r_o^2 - r_1^2} ,$$

$$B = \text{Biot number} = \frac{h \delta}{k} ,$$

$$\theta_q = \frac{q''' r_1}{2 h r_o (T_o - T_{sat})}$$

The general solution of equ. (2) is in the form,

$$\theta = C_1 e^{M_1 Z} + C_2 e^{M_2 Z} + (\theta_q + \theta_{sub})$$

where,

$$M_1 = - P/2 + (P^2/4 + B.R^{\#})^{\frac{1}{2}}$$

$$M_2 = - P/2 - (P^2/4 + B.R^{\#})^{\frac{1}{2}}$$

To show the temperature dependence of heat transfer coefficient in acurate way and also the rewetting process the cladding is divided into four region according to the surface temperature and mechanism of heat transfer, as shown in Fig. (1).

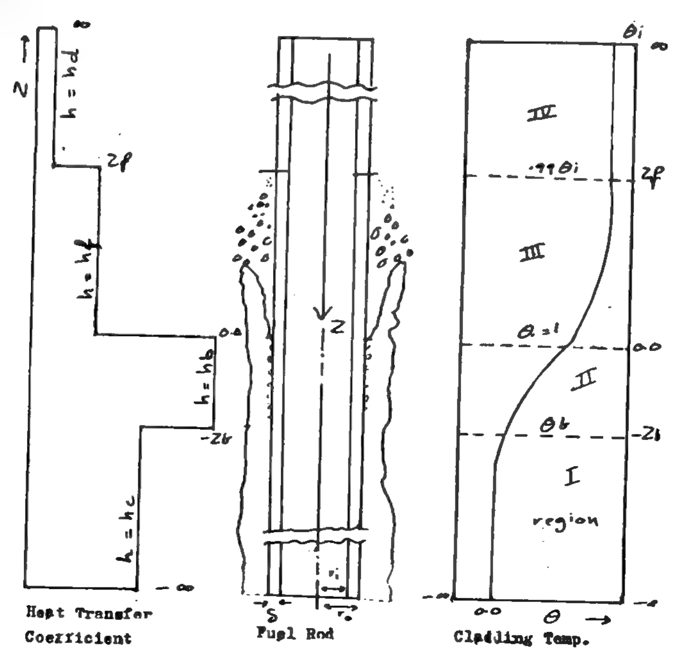

Fig.(1) Four - Regions Model

The temperature distribution in the four different regions are obtained by applying the proper boundary conditions for each region.

The boundary condition for the four regions are :

I) The non-boiling region $(-\infty \leqslant Z \leqslant -Zb)$

1) $\theta_I(-\infty) = \theta_{qI} + \theta_{sub}$.

2) $\theta_I(-Zb) = \theta_b$.

By apply the boundary condition we obtain the temperature distribution in non-boiling region in the form.

$$\theta_I(Z) = (\theta_b - \theta_{qI} - \theta_{sub})\, e^{M_{I1}(Z + Zb)} + \theta_{qI} + \theta_{sub} \quad \text{.........(3)}$$

II) The boiling region $(-Zb \leqslant Z \leqslant 0)$

The boundary conditions are

$\theta_{II}(-Zb) = \theta_b$,

$\theta_{II}(0) = 1$.

By apply the boundary condition in the general solution we obtain the temperature distribution in the boiling region as :

$$\theta_{II}(Z) = \frac{1}{A}\Big[\big[(1 - \theta_{qII})\, e^{-M_{2II} Zb} - (\theta_b - \theta_{qII})\big] e^{-M_{1II}Z} + \big[(\theta_b - \theta_{qII}) - (1 - \theta_{qII})\, e^{-M_{1II}Zb}\big] e^{M_{2II}Z}\Big] + \theta_{qII} \quad \text{.........(4)}$$

III) The fog region $(Z_f \geqslant Z \geqslant 0)$

The boundary condition are ;

$\theta_{III}(Z_f) = 0.99\,\theta_i$,

$\theta_{III}(0) = 0.0$,

substitating in the general solution to obtain the temperatur distribution in fog region

$$\theta_{III}(Z) = (1 - L - \theta_{q_{III}})\, e^{M_{III1}Z} + L\, e^{M_{III2}Z} + \theta_{q_{III}} \quad \text{........(5)}$$

where,

$$L = \frac{0.99\,\theta_i - e^{M_{III1} Zf} - \theta_{qIII}(1 - e^{M_{III1} Zf})}{e^{M_{III2} Z_f} - e^{M_{III1} Z_f}} ,$$

$$A = e^{-M_{2II}Z_b} - e^{-M_{1II}Z_b} .$$

IV) The dry region ($Z_f \leqslant Z \leqslant \infty$)

The boundary conditions are ;

$$\Theta_{IV}(Z_f) = 0.99\,\Theta_i$$

$$\Theta_{IV}(\infty) = \Theta_{q_{IV}} + \Theta_{sub} ,$$

apply the boundarycondition in general solution we get

$$\Theta_{IV}(Z) = -0.01\,\Theta_i\, e^{M2_{IV}(Z - Z_f)} + \Theta_{q_{IV}} + \Theta_{sup} \quad \ldots\ldots\ldots\ldots(6)$$

To calculate the boiling length (Z_b) and fog length (Z_f) we apply the continuity of the heat flux at the three interface between the four regions.

$$\left.\frac{d\Theta_I(z)}{dz}\right|_{z=-z_b} = \left.\frac{d\Theta_{II}(z)}{dz}\right|_{z=-z_b} \quad \ldots\ldots\ldots\ldots (7)$$

$$\left.\frac{d\Theta_{II}(z)}{dz}\right|_{z=0} \quad \left.\frac{d\Theta_{III}(z)}{dz}\right|_{z=0} \quad \ldots\ldots\ldots\ldots (8)$$

$$\left.\frac{d\Theta_{III}(z)}{dz}\right|_{z=z_f} \quad \left.\frac{d\Theta_{IV}(z)}{dz}\right|_{z=z_f} \quad \ldots\ldots\ldots\ldots (9)$$

Differentiating the equation (3) and (4) and substitating in the equation we get.

$$M_1 I\,(\Theta_b - \Theta_{qI}) = \frac{1}{A}\Big(M_{II}1\; e^{-M_{2_{II}} z_b}\big[(1 - \Theta_{q_{II}})\, e^{-M_{2_{II}} z_b} - (\Theta_b - \Theta_{q_{II}})\big] + M_{II}z\; e^{-M2_{II} z_b}\big[(\Theta_b - \Theta_{q_{II}})\; (1 - \Theta_{q_{II}})\; e^{-M_{II}1 z_b}\big]\Big) \ldots\ldots\ldots (10)$$

Differentiating equation (4) and (5) and substitating in equation (8) we get :

$$M_{III_1}\big[1 - L - \Theta_{q_{III}}\big] + M_{III}2\,L = \frac{M_{II}2}{A}\Big[(1 - \Theta_{q_{II}})\; e^{-M_{II}2 z_b} - (\Theta_b - \Theta_{q_{II}})\Big] + \frac{M_{II}2}{A}\Big[(\Theta_b - \Theta_{q_{II}}) - (1 - \Theta_{q_{II}})\Big] \ldots(11)$$

Differentiating the equation (5) and (6) and substitating in equation (9) we get

$$M_{III_1}\left[1 - L - \Theta_{q_{III}}\right] e^{M_{III}\,1\, z_f} + \left[M_{III}\, 2\, L\right] e^{M_{III}^{\,2}\, z_f} = M_{2_{IV}}\ 0.01\ \Theta_i \qquad (12)$$

Equatior (10), (11) and (12) are solved for the rewetting velocity P, the boiling length Z_b and the fog length Z_f.

3. Computer Program :-

To solve these equation first we take the value for rewetting velocity from the two - regions model, (2) with the boiling region extended to cover the whole wet region and dry region ahead of wet front as the initial, guess which is given by,

$$P = (1 - \Theta_{q_{II}})\left[\frac{Bb.\ H^{\#}}{(\Theta_i - \Theta_{q_{II}})\ (\Theta_i - 1)}\right]^{\frac{1}{2}}$$

the first guess for the boiling length is taken from the three region and dimensional model (2) given by,

$$Z_b = \frac{1}{M_{II\ 1}} \ln\left[\frac{M_{III\ 2}\,(1 - \Theta_i) - M_{II\ 2}(1 - \Theta_{q_{II}})}{M_{I\ 1}(\Theta_b - \Theta_{q_I}) - M_{II\ 2}\,(\Theta_b - \Theta_{q_I})}\right],$$

and we take the value for fog length equal 100 only just number to start by it.

Then by itration adding or substracting DALTA P (that is $P = P \pm$ DALTA P) DALTA Z_b ($Z_b = Z_b \pm$ DALTA Z_b) and DALTA Z_f ($Z_f = Z_f \pm$ DALTA Z_f), We obtain the values of P, Z_b and Z_f that satisfy the above three equations and then we calculate the value of cladding temperature distribution, for such condition.

4. Analysis of the results :-

The results from the computer programme for the one dimensional four regions model with heat generation will be analized in this section.

4.1. Rewetting velocity P :-

The variation of dimensionless rewetting velocity with the boiling Biot number B_b for different value of initial wall temperature Θ_i is given in Fig. (2) From the figure it is clear that the rewetting velocity increases with increasing the Biot number B_b because of the increased heat removal in the boiling region, the figures also show that the rate at which the rewetting P increases with B_b is larger for smaller values of Θ_i

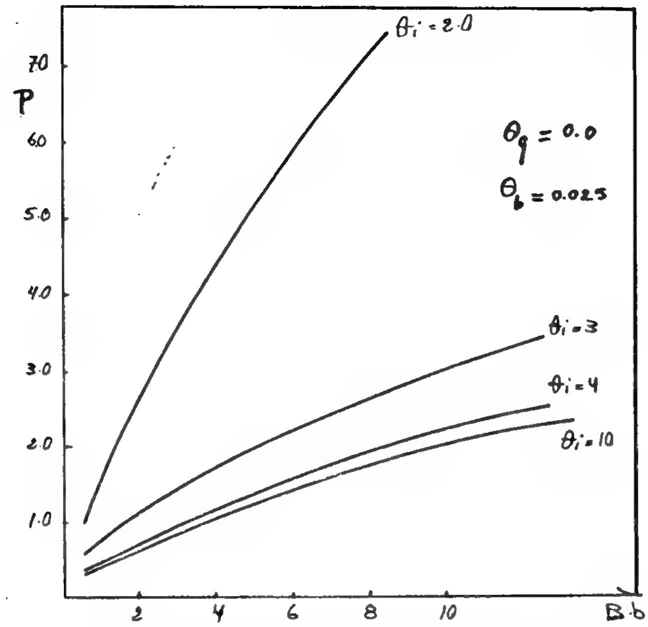

Fig.(2) Variation of the rewetting velocity with Biot Number for different θ_i .

The variation of rewetting velocity with initial surface temperature θ_i, is shown in Fig. (3) for different values of heat generation θ_q, for Biot number $B_b = 2.0$. The rewetting velocity decreases with the increase of θ_q, and it is clear that effect of θ_q, on the rewetting velocity is very small.

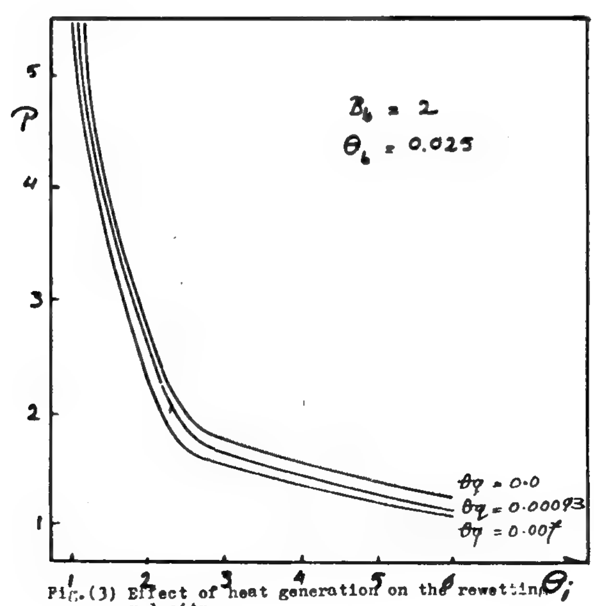

Fig.(3) Effect of heat generation on the rewetting velocity.

4.2. The Boiling Length Z_b :-

The model also examines the variation of the boiling length Z_b with the operating parameters, θ_i , θ_q and B_b. The boiling length Z_b , is plotted with the Biot number for different initial cladding surface temperatures θ_i , in Fig. (4). The results show that Z_b decreases with increasing of Biot number which can be explained by noting that increasing Biot number means increasing the heat transfer rate to the coolant in the boiling region and smaller boiling length is required to transfer the same heat flux at the wet front at the same θ_i. The figure also shows that Z_b decreases with the increase of θ_i, this decrease is smaller at bigger Biot number. This is due to the decrease of rewetting velocity with increase of initial surface temperature θ_i, that required smaller boiling region which indicates that the rewetting process is controlled mainly by θ_i.

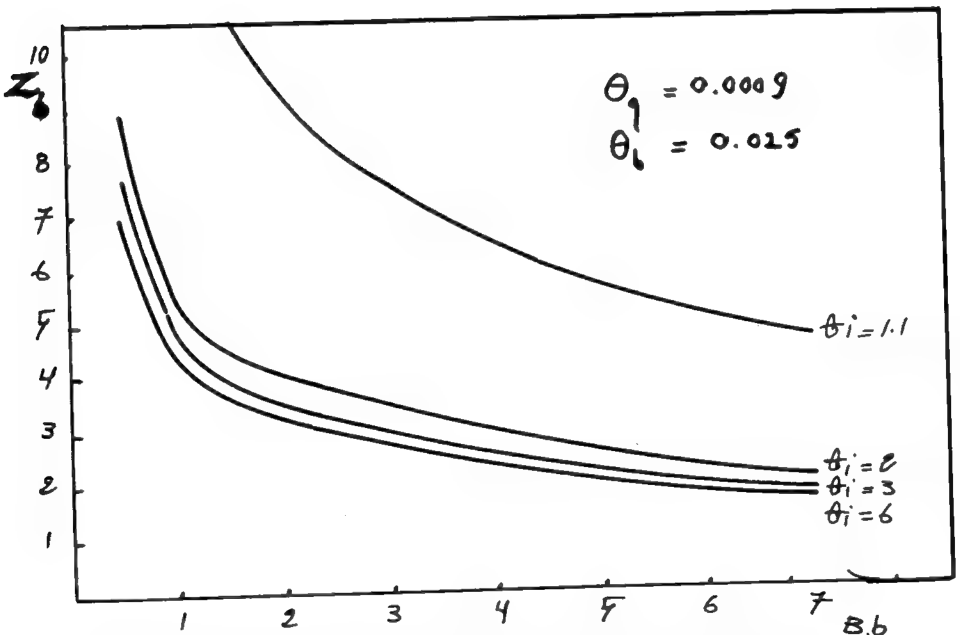

Fig.(4) Variation of the boiling length with B_b for different θ_i.

4.3 The Fog Length Z_f :-

The variation of the fog length with initial surface temperature Θ_i is shown in Fig. (5). The results show that the fog length increases with the increase of Θ_i for different value of Biot number because of the rewetting velocity decrease. The figure also shows that the fog length decreases with B_b for the same Θ_i, because of the increase of the rewetting velocity. From the above results, it can be noticed that the rewetting velocity is mainly controlled by initial surface temperature Θ_i and boiling Biot number B_b and the rewetting velocity reflects on the values of the fog length Z_f and the boiling length Z_b.

4.4 Temperature distribution :-

The axial cladding temperature distribution is shown in Fig. (6). From the figure it can be shown that the temperature distributed over large fog length for high initial surface temperature due to smaller value of rewetting velocity and over large boiling length for small value of initial surface temperature due to larger values of rewetting velocity.

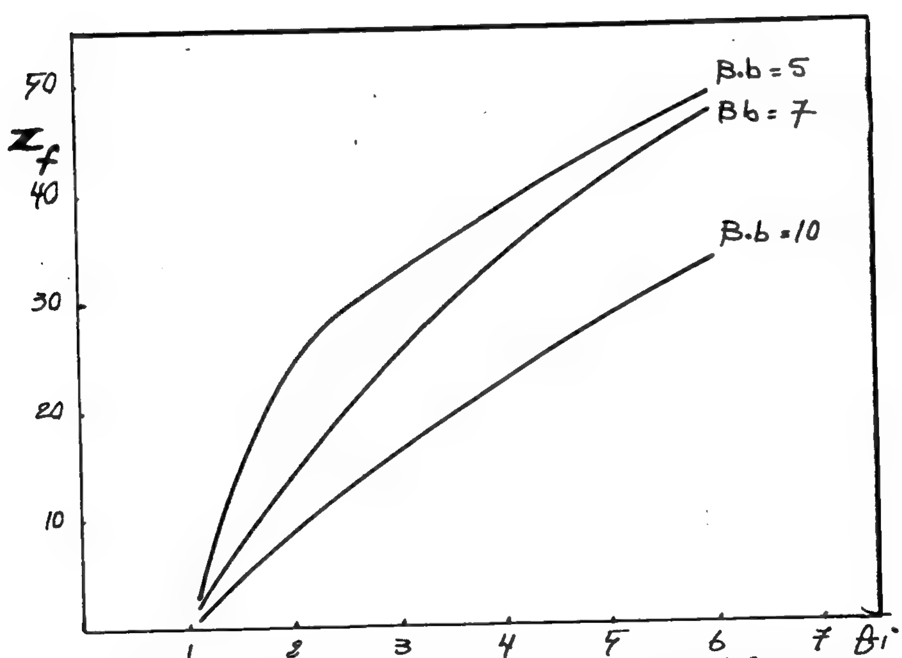

Fig.(5) Variation of the Fog Length with initial surface temp. for different B_b.

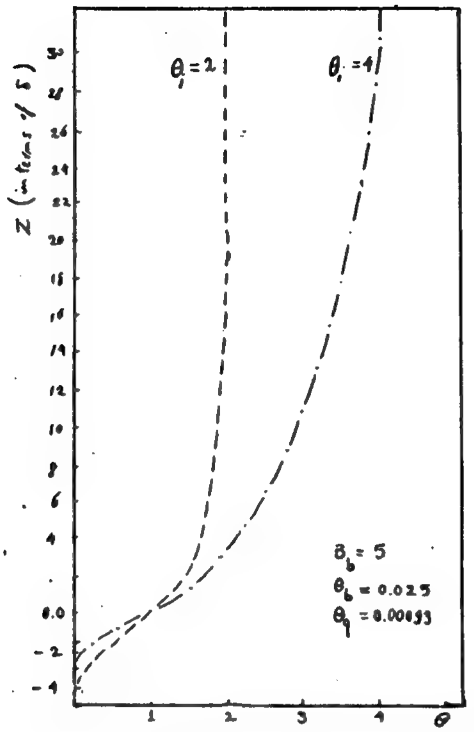

Fig. (6) Axial temperature distribution for different θ_i and with $B_b = 5$

4.5 Comparision with Two - Dimensional Models :-

Comparision between the four region one dimensional model(boiling , non-boiling, fog and dry region) with the three region two-dimensional semi-analytical model [7](non-boiling, boiling and dry) and the two dimensional two region model (boiling and fog) is[8] shown in Fig (7).

The results show that the values of rewetting velocity from one dimensional with fog zone is higher than that obtained from three regions two dimensional model without fog region due to the effect of precursory cooling, and less than that with precursory cooling with N = 100 N is the function of flow rate $N = (\frac{160}{\text{flow rate}} + 1)$ due to the effect of flow rate on the fog region. It is clear from these figure that the rewetting velocity obtained using the simple approximate one - dimensional four regions model is comparable to the more acurate two - dimensional models and the difference is small which indicates the validity of the model.

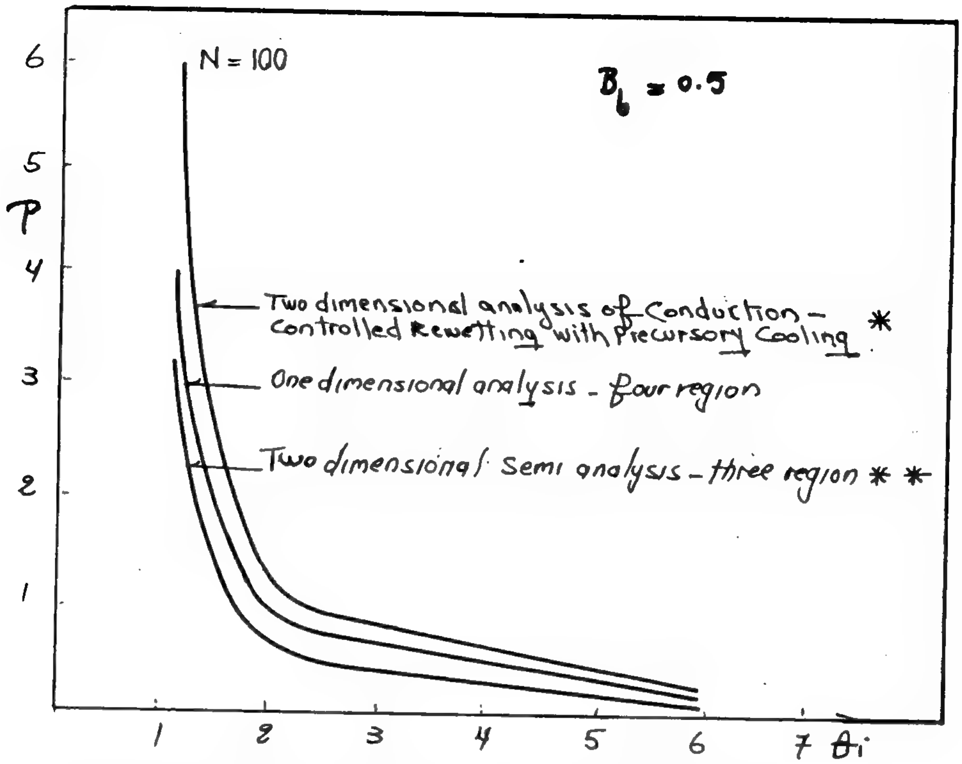

Fig.(7) Comparison between the present Model with Two-Dimensional Models.

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STEELS FOR THE PRIMARY CIRCUITS OF THE NUCLEAR POWER PLANTS

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ABSTRACT

Nowadays one of the most often utilizated sources of energy is the nuclear energy. There are many types of power reactors constructed. In most of them the different kinds of steel are used as the construction materials. There are described the selection criteria for the appropriated construction materials in the nuclear power plants, with regard to the specific conditions of their work in this paper. There are given also the specifications of the steels, their chemical compositions, mechanical and corrosion properties.

1. INTRODUCTION

Nowadays nuclear power constitutes an increasingly utilized source of energy. There are various reasons for such a fast development of nuclear power engineering, the more important one being that connected with power production costs. The unitary investment outlays decrease with the growth of the electric power of the generating plants. A comparision of the unitary investment outlays necessitated by power plants of various types shows that with the high rating power generating plants such outlays are comparable [1]. Furthermore, nuclear power plants create no nuisance connected with desulphurization and environmental pollution.
1 GW electric power plant fired with a medium-quality coal discharges

x/ Nuclear Research Centre, Tripoli-Libya, IAEA fellowship.

into the atmosphere about 10^7 tons of CO_2, 1.4×10^5 tons of SO_2 2.10^4 tons of NO_x and 4.10^3 tons of dust per year and has to be released from 3.10^5 tons of solid waste in the form of slag and ash. The extent of pollutionts is still larger in case of lignite power plants.

It should also be borne in mind that conventional power plants are fired with reservedly available fuels, i.e. with coal and crude oil whose still worthwhile deposit are being gradually depleted.

Types of power reactors as well as the criteria of their structural materials selection are described in this paper. Some more frequently applicable steel grades will be listed and their properties will be discussed.

2. THE MOST IMPORTANT TYPES OF POWER REACTORS

Many types of nuclear power reactors are now available among which water reactors have been widely applied, such as PWR /WWER/, BWR and HWR types /the latter one including CANDU type and the Soviet RBMK/ as well as those cooled with liquid metals /LMFBR/ and high-temperature, gas-cooled reactors /HTGR/.

Table 1 presents some operating date that are significant for particular water reactors.

3. CRITERIA OF MATERIAL SELECTION FOR NUCLEAR POWER INDUSTRY

Structural materials of which power reactors are made are subjected to the action of many complex factors among which it is worthwhile to mention the specific operating environment and loads producing mechanical and thermal stresses. The two basic factors to be considered in the selection of materials are:

- ionizing radiation resulting in the degradation of many characteristics,
- high degree of reliability and safety required in the operation of the equipment, involving a very careful selection of materials at the design stage as well as further thorough selection and quality inspection of semi-products and products.

Structural materials to be used in the construction of nuclear equipment and pipelines of the primary circuit have to meet a number of requirements, i.e. they have to:

1. exhibit good mechanical properties at operating temperatures,
2. be resistant to fatigue and thermal cycles and, when intended for sodium-cooled fast breeders, /with temperatures varying from 500°C to 700°C/ as well as show good creep properties, having in view expected long service life of the plant,

Table 1. Some operating data of water-cooled power reactors [2].

Parameter	PWR	BWR	HWR /Candu/
Reactor thermal power /MW/	3411	3579	2140
Reactor electric power /MW/	1100	1220	600
Power plant efficiency /%/	32	34	28
<u>Reactor pressure vessel</u>			
Outside diameter /m/	4	6	7.6
Height /m/	12	22	7,6
Wall thickness /cm/	20	14,5/16.5	3
<u>Reactor core</u>			
Diameter /m/	3.4	4.9	6,3
Active length of fuel /m/	3.7	3.8	5,9
Core weight /t/	125	238	109
Power density /kW/l/	98	54	12
Fuel assembly	15x15 open	8x8 in fuel assembly	37 in pressure tube
Fuel assembly number	193	748	4560
Total number of fuel rods	39372	46376	168720
Total weight of fuel /UO_2/t/	98	155	95
Power density in fuel /MW/t/	38	32.1	23.5
<u>Cooling system</u>			
Coolant	H_2O	H_2O	D_2O
Total water delivery /m^3/s/	17	13	11
Pressure /MPa/	15.5	7	11
Core inlet temperature /°C/	289	216	267
Core outlet temperature /°C/	325	288	312
Nominal temperature of can /°C/	347	304	362
Nominal temperature inside the fuel rod /°C/	2882	1832	2110
Maximum thermal flux on the can surface /MW/m^2/	1.4	1.08	

3. show a good resistance to corrosion in the reactor operating environment,
4. show good characteristics in the ionizing radiation field,
5. be free from strongly activating elements and from those characterized by a long half-life period,
6. show good nuclear properties, i.e. a small neutron absorption cross section which is of particular importance in case of materials intended for the construction of core elements or fuel cans in sodium-cooled fast breeder reactors,
7. be suitable for processing and, in particular, show a good weldability,
8. exhibit good thermal characteristics,
9. be readily available and ensure relatively low costs of the equipment manufacture and operation.

4. STEELS AND ALLOYS APPLIED IN THE PRIMARY CIRCUITS OF NUCLEAR INSTALLATIONS/x/

The criteria as enumerated in Paragraph 3 hereof are satisfied by various grades of steel and nickel-based alloys; that is why most of nuclear equipment is constructed of those materials. Due to high prices and the scarcity of nickel, its alloys are used only in the construction of component parts intended for high-temperature service, for cans and certain structural members in the LMFBRs as well as in high-temperature gas-cooled reactors. The PWR and BWR units are chiefly constructed of chromium-nickel or chromium-nickel-molybdenum austenitic steels or of low-alloy steels with austenitic cladding.

4.1. Low-Alloy Steels

Low-alloy steels are used in the construction of reactor pressure vessels and large size steam generator bodies provided cladding with austenitic stainless steel on the primary circuit side. For the sake of nuclear safety the risk of the rupture of the vessels, even after a long exposure, has to be practically eliminated. That is why the low-alloy steels for nuclear engineering have to meet some specific stringent requirements.

In order to improve the qualities of steel it is treated with alloying additives which can occur in solid solution, form carbides or intermetallic phases with iron or appear as non-metallic inclusions /in the

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x/ Chemical compositions and mechanical properties of selected low-alloy and stainless steels are specified in the Annexure hereto.

form of oxides, sulfides or nitrides/.
Elements such as Cr, V, Mn, Ni, Si form solid solution with iron. Cr and V result in ferrite hardening and an increase of the strength properties of steel whereas Ni and Mn extend the range of austenite occurence. Carbide formers such as Mn, Cr, V, Mo, W, Ti and Nb combine with carbon into simple or complex compounds. Simple carbides, i.e., those constituting a single element and carbon combination are, in general, sparingly soluble in austenite whereas complex carbides are characterized by a shorter stability. Certain elements can either form carbides or occur in solid solution, the ratio of alloying element content in the carbides to that in the solution depending upon the kind of heat treatment applied.

From among numerous low-alloy steels, the chromium-molybdenum grades /some times with Nb addition/ and chromium-molybdenum-vanadium grades have been applied mainly in the nuclear power engineering. The content of the alloying elements is hardly considerable and usually does not exceed 1-3%, with a total being less than 5%.

After welding and cladding the vessels are normally subjected to heat treatment in order to eliminate stresses. In most cases the heat treatment consists in annealing at 600-650 °C for about 100 hours [3]. Such an annealing can produce cracks especially in case of molybdenum-containing steels with elevated content of P, Sb, Sn and As.

Radiation is another factor likely to produce the embrittlement of low - alloy steels, and it is known to result in material hardening as well as a decrease in its plastic properties. Radiation causes also a shift of the transition temperature of steels toward higher temperature values. The effect of copper and of various other elements on irradiation embrittlement and hardening of low-alloy steels are investigated [4]. The increase of the copper content causes the transition temperature increasing for various irradiation levels. For the dose integrated during the service life of a reactors, the presence of copper corresponds to a much higher degree of hardening as compared to some other elements, such as Ni, V, Fe, P and C.
Furtheromore, bainitic or bainite-martensite structures have been found to be less sensitive to embrittlement than coars ferrite - perlite structures.

4.2. Stainless Steels

In nuclear power engineering, chromium-nickel or chromium-nickel-molybdenum stainless steels of austenitic structure are employed, the former group being used in the construction of PWR and BWR units while the latter one - in the construction of LMFBR units. The contents of chromium and nickel usually vary from 17 to 20% and from 9-14%, respectively. To ensure suitable properties of these steels, the carbon content will be adequately low /less than 0.1% with a tendency for further reduction down to the hundreth parts of percent/.

The steels are stabilized with titanium or niobium to reduce the carbon content in the solution and thus increase the resistance to intercrystalline corrosion. An addition of molybdenum to chromium-nickel steels increase their resistance to creep and stress-corrosion and that is why the Cr-Ni-Mo steels are applied in the construction of reactors operating at higher temperatures.

Owing to their application in the nuclear reactor systems additional limitations are imposed on the content of certain strongly activating elements, such as Mn, Ta, As and Co /Mn and As are characterized by short half-life periods whereas Co and Ta are activating more slowly but their half-life periods are long/. In practice the content of Co and Ta is reduced to less than 0.08% and 0.05%, respectively.

Boron content is also limited in these steels, because of $^{10}B/n,\alpha/^{7}Li$ reaction producing helium which could cause material cracking.

The structure of stainless steels is assumed to be austenitic. Depending upon its chemical composition the steel can contain a certain amount of high-temperature δ - ferrite, whose approximate content can be determined from Schaeffler's or De Long's diagrams on the basis of chromium equivalent /ferrite-forming elements/ and nickel equivalent /austenite-forming elements/ calculated [5] . It should be noted that the content of δ -ferrite depends also on the rate of cooling.

After prolonged effect of high temperatures the stainless steels can be exposed to aging, i.e., the precipitation of interstitial compounds /carbides, nitrides/ or intermetallic phases /σ, χ, η and ξ/. Thus, an annealing within 450-900 °C temperature range leads to the precipitation of $M_{23}C_6$ carbides followed by χ - and η - phase precipitation. After longer time-periods, M_6C type carbides can also appear. At higher temperatures the sequence of precipitation changes to start with $M_{23}C_6$ carbides followed by χ - phase and σ - phase [6,7] . According to numerous research studies a cold plastic strain applied prior to aging is favourable for precipitation processes, whereas a rise in carbon content in steel accelerates the precipitation of carbides and makes the precipitation of intermetallic phases delayed [8] .

The stainless steel structure free from secoundary precipitations is obtained by a solution heat treatment at 1000-1150 °C followed by quenching in water or in air, the latter method being applied in case of very thin elements.

Stainless steels have good mechanical properties and their relatively high tensile strength /R_m= 480-670 MPa/ is accompanied by good plastic characteristics /A_5 = 40-60%/. They also exhibit good resistance to fatigue and creep which is of vital importance in case of LMFBRs.

Irradiated stainless steels undergo hardening, i.e., their strength properties increase along with a drop in their plastic properties.

Stainless steels are characterized by good corrosion resistance both in PWR and BWR units environment and in liquid metals.

Experimental findings have shown that the corrosion occuring in the operating environment of PWR primary circuit is low and its yearly rate does not exceed 0.0005-0.0016 mm [9] .
This leads to the conclusion that with the predetermined service life of nuclear power plants this general corrosion creates no hazard.
The corrosion rate, however, becomes considerably accelerated in crevices /being as many as five times faster/ and in case of high-velocity medium flow accompanied with erosion. Under the latter circumstances the surface of steel can be deprived of its protective film whereby the corrosion rate will grow. Such phenomena are observed most frequently in heat exchangers since the corrosion rate reaches its maximum on bends. That is why the constructional codes for heat exchangers determine the permissible bending radius for the tubes.

Stainless steels may also suffer from other types of corrosion, of which intercrystalline corrosion and stress-corrosion cracking should be mentioned. Where intercrystalline corrosion occurs the boundaries of grains are attacked. This type of corrosion does not involve a loss in weight and is hardly noticeable. At the begining it is manifested by a drop in strength and eventually, in some drastic cases, it can cause the material to disintegrate.

The changes provoked by intercrystalline corrosion in stainless steels are determined by the examination of structure, changes in specific resistance or by sound testing. It is belived that intercrystalline corrosion is caused by the precipitation of carbides along the grain boundaries whereby these latter become depleted of chromium.
The theory of depletion is the most popular one, and the other theories concerning the mechanism of intercrystalline corrosion have insufficient documentary support. All the theories, however, do concur in recognizing that the occurence of intercrystalline corrosion is connected with prolonged annealing of steel within the sensitization temperature range. Which is why the stainless steels are subjected to solution heat treatment. This is of particular importance in case of welded elelemts since welding involves similar processes. It should be stressed that steels with a lower carbon content /about 0.03%/ are less sensitive to intercrystalline corrosion.

The other type of corrosion dangerous for stainless steels, i.e., stress-corrosion cracking is related to the interaction of the environment and external or internal tensile stresses. This interaction occurs in the presence of chlorides, with a low concentration of chloride ions in oxidated solution being able to produce stress corrosion. This type of corrosion occurs in heat exchangers and steam generators at the stress concentration areas, a long initial stage of this process being followed by fast propagation of the crevice resulting in material cracking. Combined welding of stainless steel with other steel grades should be avoided since such a welding process is connected with the occurence of stresses.

When subjected to the action of liquid metals the stainless steels exhibit a slight general corrosion, whose rate is markedly influenced by the content of impurities, and particularly of oxygen, in liquid sodium. It is mass transfer phenomena connected directly with the selective dissolution of steel components in a liquide sodium that are essential in this operating environment. Particularly dangerous in this case are the processes of carburization of steels whereby their mechanical properties are significantly affected. Carburization of low-carbon stainless steel increases its tensile strength but reduces its plastic properties. Carburized layers are favourable for the formation of carbides and σ-phase. Decarburization occurs mainly in non-stabilized steels [10,11] .

When contacting with liquid sodium in the LMFBRs stainless steels may also undergo intercrystalline corrosion in cases where precipitations occur along the grain boundaries. On the other hand the creep rates of stainless steels in liquid sodium and in air have been found not to differ from one another.
The effect of sodium becomes noticeable in cases when it is strongly polluted, particularly with oxygen and carbon. The processes of stainless steel carburization and decarburization have been found to intensify with the specimens being subjected to stresses [11] .

5. STEEL PRODUCTS APPLIED IN THE PRODUCTION OF NUCLEAR POWER EQUIPMENT

Nuclear power equipment is manufactured from a large variety of steel products. Those of stainless steels include:
- sheets and plates,
- light and heavy-wall tubes and pipes intended for heat exchangers and steam generators,
- heavy-wall and large diameter pipes intended for main pipelines,
- forgings with a large dimensional range.

Low-alloy steels are utilized mainly in the production of pressure vessels. The size of reactor vessels increases with reactor power, as can be seen from the table below, based on the PWRs [9].

Reactor power [MW] / Reactor vessel dimensions [mm]	200	500	3000
Diameter	3558	5338	9750
Height	12505	18300	90500
Wall thickness	125	265	300

The properties of all steel products must be checked and found in compliance with the specified requirements. Materials are inspected in

accordance with the nuclear safety and quality securing rules using both non-destructive and destructive testing methods.

6. SUMMARY

In nuclear power engineering use is made of steels commonly applied in other branches of industry are used. The only restriction concerns special limitations of certain impurities /such as Co, Ta, Cu, B/.

High quality of steel products is of vital importance. Particular care should be exercised throughout their whole production process in the mill including steel making, further plastic working as well as transport and storage.

It should be emphasized that the development of nuclear power engineering constitutes a stimulus for other industrial branches, especially for metallurgical and machine-building ones.

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TABLE A. Chemical composition of low alloy steels.

	Country	Grade	Contains in weight %									
			C max	P max	S max	Mn	Si	Cr	Ni	Mo	V	Cu max
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Poland	24H2MF	0.20-0.30	0.030	0.030	0.5-0.80	0.17-0.37	2.1-2.5	-	0.9-1.2	0.3-0.6	
	USSR	15X2MΦA	0.13-0.18	0.025	0.025	0.30-0.60	0.17-0.37	2.5-3.0	≥0.4	0.6-0.8	0.25-0.35	≥0.025
		15X2MΦA-A	0.13-0.18	0.012	0.015	0.30-0.60	0.17-0.37	2.5-3.0	0.4	0.5-0.7	0.1-0.12	0.10
	England	897M39	0.35-0.43	0.035	0.035	0.45-0.7	0.1-0.35	3.0-3.5	0.4 max	0.80-1.1	0.15-0.25	-
	France	20CDV5.08	0.17-0.24	0.030	0.030	0.30-0.60	0.30-0.60	1.10-1.50	≤0.5	0.70-1.0	0.20-0.40	-
	FRG	27CrMoV612	0.45-0.55	0.030	0.030	0.50-0.80	0.2-0.5	3-3.60	-	1.2-1.60	0.05-0.25	-
2	Poland	10H2M	0.08-0.15	0.030	0.030	0.4-0.60	0.15-0.5	2.0-2.5	0.30	0.9-1.1	-	0.25
	USA	A542-4	0.15	0.035	0.035	0.30-0.60	0.15-0.30	2.0-2.5	-	0.9-1.10	-	-
	France	10CD9.10	0.17	0.030	0.030	0.4-0.85	0.10-0.4	2.0-2.5	-	0.9-1.15	-	-
	FRG	10CrMo9.10	0.15	0.04	0.04	0.4-0.60	0.15-0.5	2.0-2.5	-	0.9-1.1	0.04	-
3	Poland	K22H	0.10-0.18	0.045	0.045	0.80-1.10	0.17-0.37	0.30	0.30	0.25-0.40	-	0.30
	USSR	22K	0.19-0.26	0.025	0.025	0.75-1.00	0.2-0.4	0.40	0.30	-	-	0.30
		25X1MΦ	0.22-0.29	0.030	0.025	0.40-0.70	0.17-0.37	1.5-1.8	0.30	0.25-0.35	0.15-0.30	-
	USA	A508-3	0.15-0.25	0.025	0.025	1.20-1.50	0.15-0.35	-	0.40-0.80	0.40-0.60	<0.05	-
		A533-B	0.25	0.035	0.040	1.15-1.50	0.15-0.30	-	0.40-0.70	0.45-0.60	-	-
	France	18MD4.05	0.20	0.030	0.30	0.9-1.40	0.15-0.35	-	-	0.40-0.60	-	-
	FRG	19Mn5	0.17-0.22	0.045	0.045	1.0-1.30	0.30-0.6	0.30	-	-	-	-
4	Poland	32HN3M	0.28-0.35	0.040	0.030	0.30-0.60	0.17-0.37	0.6-0.90	2.75-3.25	0.30-0.60	-	-
		22H2NM	0.18-0.25	0.035	0.035	0.4-0.60	0.1-0.4	1.2-2.0	0.9-1.1	0.5-0.8	0.05	-
	USSR	15X3HMΦA	0.12-0.16	0.020	0.020	0.30-0.60	0.17-0.37	2.2-2.7	0.8-1.30	0.5-0.80	0.05-0.15	0.15
		15X2H1ΦA	0.12-0.16	0.020	0.020	0.30-0.60	0.17-0.37	1.70-2.20	0.80-1.50	0.80-1.10	0.08-0.15	0.15
		10GW2MFA	0.08-0.11	0.02-0.01		0.8-0.94	0.17-0.42	0.30	2.0-2.7	0.70-0.50	0.07-0.064	0.30
	USA	A543	0.23	0.02	0.02	0.4	0.18-0.37	1.44-2.06	2.93-3.07	0.41-0.64	0.03	-
	France	30CND8	0.26-0.33	0.030	0.025	0.30-0.60	0.10-0.40	1.80-2.20	1.80-2.20	0.3-0.5	-	-

TABLE B Mechanical properties of low alloy steels.

	Country	Grade	Tensile Strength R_m min MPa	Yield Strength R_e MPa	Elongation A min %	Reduction %	Hardness	Heat Treatment
1	2	3	4	5	6	7	8	9
1	Poland	24H2MF	740	590	15	-	215-249HB	-
	USSR	15X2MΦA	568-735	431	23	50	-	Normalized 900°C, Relaxation 660°C.
		15X2MΦA-A						
	England	897M39	850-1000	640	13	-	248-302HB	Hardened in oil 920-970°C, Tempered at 550-720°C.
	France	20CDV5.08	776-815	608	16	-	-	Hardened 950-1000°C, Tempered 700-750°C.
	FRG	27CrMoV612						
2	Poland	10H2M	440-590	265	20-18	-	140-180HB	-
	USA	A542-4	586-723	413	-	-	-	Normalized at 950°C, Relaxation at 740°C.
	France	10CD9.10	510-610	295	22	-	-	Normalized at 925°C, Relaxation at 660°C.
	FRG	10CrMo9.10						
3	Poland	K22H	411-529	255	-	-	-	Normalized at 900°C, Relaxation at 660°C.
	USSR	22K	431-588	226	-	45	-	Normalized at 900°C, Relaxation at 660°C.
		25X1MΦ	784	618-784	16	50	241-286HB	-
	USA	A553-B	552-689	345	20	-	-	-
		A533-B	550	345	18	-	-	
	France	17MD4.05	509.5-607.6	345	-	-	-	Normalized at 875-925°C air or soften at 600-675°C.
	FRG	19Mn5						
4	Poland	32HN3M	880	740	15	40	270HB	-
		22H2NM	740	500	17	-	-	-
	USSR	15X3HMΦA	600	500	14	60	-	Hardened at 920°C, Relaxation at 645°C.
		15X2HM1ΦA	650	550	14	60	-	Hardened at 920°C, Relaxation at 645°C.
		10GW2MFA	-					-
	USA	A543	724-862	586	14	-	-	Hardened 850°C, /oil/ Relaxation at 600°C.
	France	30CND8	1030-1330	930	11	-	-	

TABLE C. Chemical composition of stainless steels.

	Country	Grade	Contains in weight %									
			C max.	P max.	S max.	Mn	Si	Cr	Ni	Mo	Ti	Nb
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Poland	OH18N9	0.07	0.030	0.025	1.0-2.0	0.8	17-19	9-11			
	USSR	OX18H10	0.08	0.035	0.020	1.0-2.0	0.8	17-19	9-11			
	USA	304	0.08	0.045	0.030	2.0	1	18-20	8-12			
	England	304S15	0.06	0.045	0.030	0.05-2	0.2-1	17.5-19	8-11			
	France	Z6CN18.09	0.07	0.040	0.030	2	1	17-19	8-11			
	FRG	X5CrNi18.09	0.08			2	1	17-20	8.5-10.5			
2	Poland	OOH18N10	0.030	0.450	0.030	2	0.8	17-19	10-12			
	USSR	OOX18H10	0.040	0.035	0.020	1-2	0.8	17-19	8-11			
	USA	304L	0.030	0.045	0.030	2	1	18-20	8-12			
	England	304S11	0.0[illegible]0	0.040	0.030	0.5-1.0	0.2-2	17.5-19	9-12			
	France	Z2CN18.10	0.030	0.040	0.030	2.0	1.0	17-19	9-11			
	FRG	X2CrNi18.09	0.030			2.0	1.0	17-20	10-12.5			
3	Poland	OH18N10T	0.080	0.030	0.025	1-2	0.8	17-19	9-11		5xC< 0.7	
	USSR	OX18H10T	0.080	0.030	0.025	1-2	0.8	17-19	9-11		5xC< 0.7	
	USA	321	0.080	0.045	0.030	2	1	17-19	9-11		5xC< 0.7	
	England	321S31	0.080	0.045	0.030	0.5-2	0.2-1	17-19	9-12		5xC< 0.7	
	France	Z6CNT18.11	0.080	0.040	0.030	2	1	17-19	11-13		5xC< 0.7	
	FRG	X5CNT18.10	0.080	0.045	0.030	2	1	17-19	9-12		5xC< 0.7	
4	Poland	OH18N12Nb	0.080	0.035	0.030	1-2	0.8	17-18	10-13			8xC < 1.2
	USSR	OX18H12	0.080	0.035	0.020	1-2	0.8	17-18	11-13			8xC < 1.2
	USA	347S31	0.080	0.045	0.030	2	1	17-19	9-13			>10xC < 1.00
	England	347S17	0.080	0.045	0.030	0.5-1	0.2-1	17-19	9-12			>10xC < 1
	France	Z6CNNb18.11	0.080	0.040	0.030	2	1	17-19	10-12			>10xC < 1
	FRG	X10CrNiNb1809	0.10			2	1	17-19	9-11.5			> 8xC
5	Poland	H17N13M2T	0.08	0.045	0.030	2	0.80	16-18	11-14	2.0-2.5	5xC -0.7	
	USSR	10X17H13M3T	0.08	0.035	0.020	2	0.80	16-18	12-14	2.0-3.0	5xC-0.07	
	USA	316	0.08	0.045	0.030	2	1	16-18	10-14	2.0-3.0		
	England	316S31	0.07	0.045	0.030	0.5-2	0.2-1	16.5-18.5	10-13	2.25-3		
	France	Z6CND17.11	0.070	0.040	0.030	2	1	16-18	10-12.5	2-2.5		
	FRG	X5CrNiMo18.10	0.070			2	1	16.5-18.5	10.5-13.5	2-2.5		
6	Poland	OOH17N14M2	0.030	0.035	0.030	2	0.8	16-18	12-15	2-2.5		
	USSR	03X17H19M3	0.030	0.035	0.020	1-2	0.4	16-18	13-15	2.5-3.1		
	USA	316L	0.030	0.045	0.030	2	1	16-18	10-14	2-3		
	England	316S11	0.030	0.045	0.030	0.5-2	0.2-1	16.5-18.5	11-14	2.25-3		
	France	Z2CND17.12	0.030	0.040	0.030	2	1	16-18	11-13	2-2.5		
	FRG	X2CrNiMo17.13	0.030			2	1	16.5-18.5	11-14	2-2.5		
7	Poland	OH17N12M2T	0.05	0.045	0.030	2	1	16-18	11-14	2-3	5xC<0.6	
	USSR											
	USA	316T	0.08	0.045	0.030	2	1	16-18	10-14	2.0-3.0	5xC	
	England	320S31	0.08	0.045	0.030	2	1	16.5-18.5	10.5-13.5	2-2.5	5xC	
	France	Z6CNDT17.12	0.08	0.040	0.030	2	1	16.5-18.5	11-14	2-2.5	5xC	
	FRG	X10CrNiMoTi18.10	0.1			2	1	16.5-18.5	10.5-13.5	2-2.5	5xC	

TABLE D. Mechanical properties of stainless steels.

	Country	Grade	Tensile Strength R_m min MPa	Yield Strength $R_{0,2}$ min MPa	Elongation A min %	Reduction Z min %	Hardness	Heat Treatment
1	2	3	4	5	6	7	8	9
1	Poland	OH18N9	540	200	45	60		annealing 1030-1070°C water or air
	USSR	OX18H10	480	200	40	55		
	USA	304	540	210	60		80HRB	
	England	304S15	480	195	40		183HB	softening temperature 1000-1100°C
	France	Z6CN18.09	590	220	45			annealing 1025-1075°C
	FRG	X5CrNi 18.09	500-700	200	50		130-180HB	annealing 1000-1050°C
2	Poland	OOH18N10	441	177	40		116-207HB	annealing 1050-1100°C
	USSR	OOX18H10	450	160	40			annealing 1030-1100°C water or air
	USA	304L	550	210	55	20	76HRB	
	England	304S11	480	180	40		183HB	softeing temperature 1000-1100°C
	France	Z2CN18.10	470-670	190	45			annealing 1000-1100°C
	FRG	X2CrNi18.09	441-686	176,5	45			
3	Poland	OH18N10T	550	200	45			annealing 1100-1150°C water
	USSR	OX18H10T	500	200	40	50		annealing 1050-1100°C water or air or oil
	USA	321	600	250	55		80HRB	
	England	321S31	510	200	35		183HB	softening temperature 1000-1100°C
	France	Z6CNT18.11	590-686	220	45			annealing 1050-1100°C
	FRG	X5CNT18.10	539-825	215,6	40			
4	Poland	OH18N12Nb	490	206	40		121-207HB	annealing 1050-1100°C water
	USSR	OX18H12	500	180	40	55		annealing 1050-1100°C water or air
	USA	347	590	280	50		84HRB	
	England	347S31	510	205	30		183HB	
	France	Z6CNNb18.11	500	200	40			annealing 1075-1125°C water
	FRG	X10CrNiNb18.09	500-750	210	40		130-190HB	
5	Poland	H17N13M2T	510	215	40	55		after annealing 1000-1100°C water
	USSR	10X17H13M3T	530		35		80HRB	
	USA	316	590	240	55			
	England	316S31	510	205	40		183HB	softening temperature 1000-1100°C
	France	Z6CND17.11	590	220	50			annealing 1050-1100°C
	FRG	X5CrNiMo18.10	490-686	205	45		130-180HB	
6	Poland	OOH17N14M2	600	300	55		150Hv	
	USSR	O3X17H14M3						
	USA	316L	550	210	55		76HRB	
	England	316S11	490	190	40		183HB	softening temperature 1000-1100°C
	France	Z2CND17.12	600	300	45			
	FRG	X2CrNiMo17.13.2	490-690	190	40			annealing 1000-1100°C
7	Poland	OH17N12M2T	440	195	45			annealing 1050-1100°C
	USSR							
	USA							
	England	320S31	510	210	35		183HB	softening temperature 1000-1100°C
	Frence	Z6CNDT17.12	550-750	225-235				
	FRG	X10CrNiMoTi18.10	490-625	225,4	40		130-190HB	

PROSPECTS OF THERMONUCLEAR ENERGY

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1. INTRODUCTION

According to estimations [1], the total energy consumption rate of the world will be in the order of 30 TW (1 TW = 10^{12} Watt) by the year 2025. We will not discuss renewable energy sources like solar or wind energy, which can be used in some parts of the world but we will discuss the situation with fossil fuels.

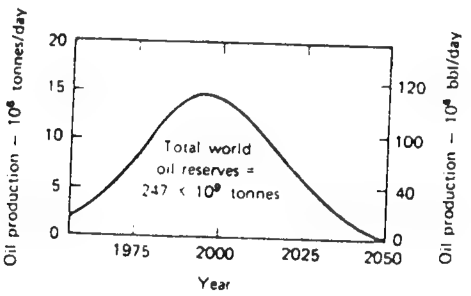

Fig. 1. Estimates of the world crude oil production rates for the future [1]

Figure 1 shows estimates of the world crude oil production rates for the future. Production will probably decline after the year 2000, and, by the year 2050 oil reserves will be exhausted. Coal reserves can be enough for the 21st century. An obvious disadvantage of these fuels is the increase of CO_2 concentration in atmosphere when they are burned. If CO_2 concentration becomes too high [1], changes in climate could take place. And that restricts the utilization of these fuels to the level of about 10 TW. Thus, fossil fuels cannot meet the requirements of total power consumption after the year 2000.

The situation with nuclear fission fuels is somewhat better. Although the reserves of U-235 are estimated by 300 TW only, the reserves of U-238

and Th-232 which are estimated by 3.10^5 TW can satisfy the energy requirements for 10 thousand years. However, nuclear energetics has serious problems connected with the disposal of large amounts of radioactive waste plus the risk of possible accidents.

An alternative source of energy is the thermonuclear fusion to which we devote our paper. Fuel of thermonuclear fusion is the hydrogen isotopes namely, deuterium, D, and tritium, T. Reserves of deuterium are 2.10^{11} TW in sea water and reserves of lithium for the production of tritium are 6.10^8 TW. Thus, thermonuclear fusion energy presents an infinite source of energy and can meet all energy needs for an indefinite period of time.

An advantage of a thermonuclear reactor is its radiation safety because it does not produce long-lived radioactive elements, that is, there is no high-radioactive waste. Accidents of an explosion type are unthinkable because thermonuclear reaction is ceased immediately in case of any violation in the working conditions of a reactor.

2. PHYSICAL BASIS OF A THERMONUCLEAR REACTOR

The basis of the thermonuclear energy is the fusion reaction between light elements to form heavier ones and the release of large amounts of energy. The most promising reaction in this context is the D-T reaction due to its low ignition parameters, which produces α particle and fast neutron n according to

$$D + T \rightarrow (\alpha + 3,52\ \text{MeV}) + (n + 14,06\ \text{MeV}) \tag{1}$$

Neutrons are slowed down in lithium and initiate the exothermic reaction:

$$n + Li^6 \rightarrow \alpha\,(2,1\ \text{MeV}) + T\,(2,7\ \text{MeV}) \tag{2}$$

These two reactions provide the thermonuclear energy and the reproduction of tritium respectively.

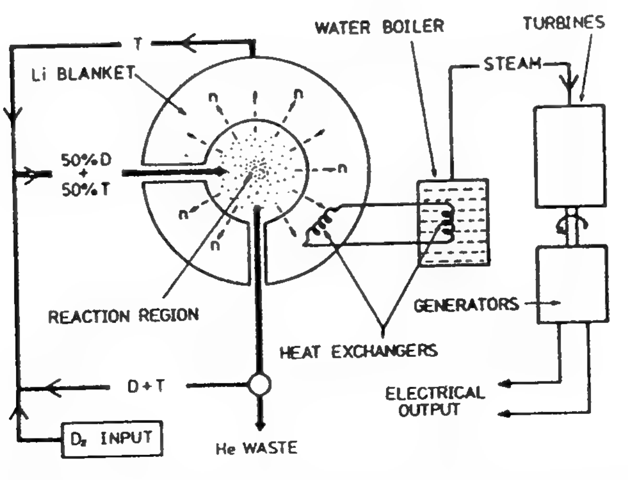

Fig. 2. A simplified cycle for fuel and reaction products in a D-T fusion power reactor [2].

Figure 2 shows a highly simplified diagram of the flow cycle of fuel and reaction products for a continuously operated thermonuclear reactor [2]. A mixture of 50% D and 50% T gas is fed into a reactor vessel, where suffi-

cient energy is introduced for the fusion reaction to take place. The 14,06 MeV neutrons released in the reaction readily pass through the walls of the vessel and enter the surrounding blanket that contains lithium. This blanket serves the dual purpose of neutron absorber and tritium breeder. For the lithium blanket the practical energy yield is ~20 MeV per fusion event. The deposited energy heats the blanket from which energy is extracted by circulation of a heat exchange fluid. This fluid transfers heat to steam turbines and electric generators. Any unburned fuel together with He arising from D-T fusion is exhausted from the reactor vessel and recycled after the He has been separated and extracted as waste and D-T mixture is enriched with tritium.

The total number of DT reactions per unit volume is proportional to $N_D \cdot N_T \cdot t$; where $N_{D,T}$ = density of D and T nuclei and t is the temperature of the mixture. The thermonuclear reaction is carried out in a dense plasma in order to have a large number of fusion events. Plasma is a gas consisting of deuterium and tritium ions and electrons. The maximum energy output of the DT reaction at minimum $N \cdot \tau$ product is obtained at plasma temperature t = 7-20 KeV (~80-200 million degrees).

The idea of self-sustaining the thermonuclear reaction (1) presupposes that the produced α-particles deposit their energy into plasma and this compensates for all energy losses from plasma due to heat conduction, diffusion, radiation and so on. Energy balance results in a Lawson criterion, that is:

$$N \cdot \tau_e \geqslant 2.10^{20} \quad m^{-3}.s$$

Where $N = N_{D,T}$, τ_e is the energy confinement time in plasma. There are two ways to realize this criterion. The first way is to produce very dense plasma ($N > 10^{26}$ m^{-3}) by compressing matter to high density like that in laser fusion. This way is called "inertial confinement". The second way is to increase τ_e at moderate plasma density. For this purpose plasma must be contained in a magnetic trap for 1-2 seconds. We shall discuss this very method which is called "magnetic confinement".

3. TOKAMAK

The ability of a magnetic field to restrict the transverse motion of a charged particle is the basic idea of magnetic confinement and thermal insulation of plasma. The trajectories of charged particles in magnetic field are spirals around the magnetic lines of force. To eliminate end plasma losses the magnetic lines of force are bent into a circle. However, this results in a higher diffusion of plasma across the magnetic field due to the inhomogeneous magnetic field produced in this way. It is possible to decrease diffusion across the field lines by creating toroidal rotational transform. This idea can be realized by twisting the magnetic field lines around the torus. One of the ways to create a rotational transform is by running an electric current in plasma along the magnetic field lines which produces a circular magnetic field. Such a plasma trap is called a "TOKAMAK" and it was proposed by the Soviet scientists at the beginning of the fifties [3].

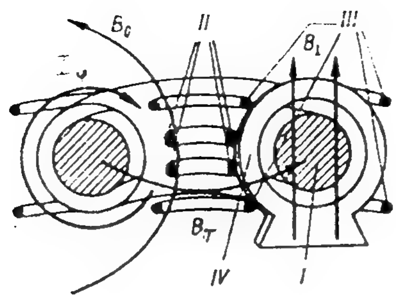

Fig. 3. The functional diagram of Tokamak [4]

Figure 3 shows the functional diagram of the Tokamak installation. Plasma ring I, is created by the breakdown of DT gas mixture in an electric field induced by an alternating flux of the magnetic field B_0 of the inductor II. The toroidal magnetic field TF is created by running a current I_φ in the coils IV. The breakdown of the gas creates plasma with plasma current I_p along the magnetic field B_T.

After Tokamak was invented, several basic plasma physics problems had to be solved and, in particular, problems of the Tokamak physics. The main problems were equilibrium, stability and diffusion of plasma. In order to reach equilibrium it is necessary to compensate for all the forces acting on the plasma ring. The problem was solved by using control coils arranged around the plasma creating control field, $B_\perp$ (III in Fig. 3) and by a copper shell for the fast control of plasma position employing the Foucault currents induced in the shell.

Let us assume that equilibrium is established. Will this state of plasma be maintained stable? There are two sources of energy which can make plasma unstable in a Tokamak. These are the heat energy of plasma and the magnetic energy associated with plasma current. Heat energy is the reason for the flute and drift instabilities. Magnetic energy leads to the development of magnetohydrodynamic (MHD) screw instabilities. Large scale instabilities are the most dangerous. Such an instability is the dissipative screw tearing instability which results in the destruction of magnetic surfaces and formation of magnetic islands. This significantly increases particle and energy transport across the magnetic field. Screw instability is slow and can be stabilized by choosing the safety factor, $q = a^2 B_T/RI_p$ where a and R - minor and major radii of plasma.

Disruptive instability is the most fast and powerful instability. It results in fast cooling of large plasma regions. It is a marginal case of the tearing instability development. It results in limiting the magnitude of plasma current and can destroy the vacuum chamber of a Tokamak.

Diffusion and conduction define plasma confinement when equilibrium is reached. The main channel of energy loss from plasma in a Tokamak is the electron heat conduction.

The history of a Tokamak development goes back to the year 1955 and started in the USSR. International interest in Tokamak arose after the IAEA conference in 1968 in Novosibirsk where high Tokamak plasma parameters

were reported. Since then, many Tokamaks have been built all around the world. Figure 4 gives size comparison of some Tokamaks available today.

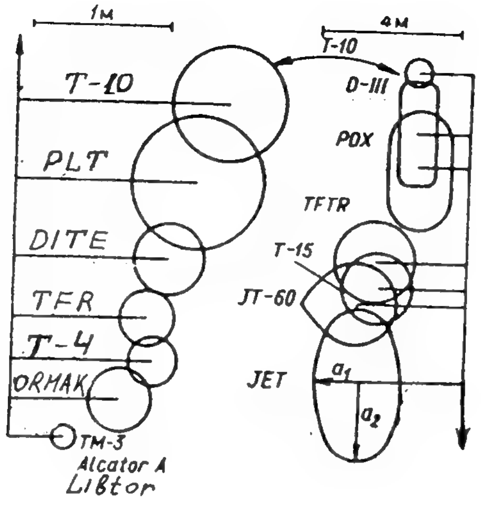

Fig. 4 Dimensions of chambers cross-sections of some Tokamaks [4]

Libtor was built in Tajura, Libya where research on Tokamak plasma is carried out in topics like distruptive instability and plasma-wall interactions [5-8].

Plasma parameters near the desired values for selfsustained fusion reaction have been obtained on large Tokamaks. For example, ion temperature $\sim$ 22 KeV was obtained on TFTR, and on JET, confinement times of $\sim$ 1 s were reported. The USSR, USA, Europe and Japan are cooperating their efforts to build the International Tokamak Experimental Reactor (ITER) which will have the size of a minor radius a $\gtrsim$ 1.5 m and a major radius R $\gtrsim$ 5 m. The future program of a thermonuclear fusion is aimed at building a power station for which reason many serious engineering problems have to be solved.

4. ENGINEERING PROBLEMS

The commercial utilization of nuclear fusion power is still a long way in future. This is due to different components which enter in the construction of the fusion power plant. Table I shows major design parameters for a fusion reactor [1]. In spite of the large effort on national and international levels, there still exist certain problems relevant to the reactor components that must be solved by fusion research and development (R & D). A major feature [9] of the R & D framework developed for fusion nuclear technology is the utilization of nonfusion facilities (non-neutron test facilities, fission reactors and accelerator-based neutron sources) over the next 15 years followed by testing in a fusion device beyond the year 2000.

Table 1
STARFIRE Major design parameters 1980 [1]

Net electrical power, MW	1200
Gross electrical power, MW	1440
Fusion power, MW	3510
Thermal power, MW	4000
Gross turbine cycle efficiency, %	36
Overall availability %	75
Average neutron wall load, MS/m^2	3.6
Major radius, m	7.0
Plasma half-width m	1.94
Plasma elongation b/a	1.6
Plasma current MA	10.1
Average toroidal beta	0.067
TF on axis, T	5.8
Maximum toroidal field T	11.1
No. of TF coils	12
Plasma turn mode	Continuous
Current drive and heating method	66 MW rf at 1.6 G Hz (lower hybride)
Plasma startup	ECRH-assisted, limited OH coil
TF Coils material	Nb_3Sn/a b Ti/Cu/SS
Blanket structural material	PCA, an austenitic S.S.
Tritium breeding medium	Solid breeder (α-$LiAlO_2$)
Wall/blanket constant	Pressurised water
Plasma impurity control	Limiter and vacuum system supplemented by Low coating enhanced radiation and magnetic field margin
Primary vacuum boundary	Inner edge of shield

It is work mentioning here that vacuum technology is developed and it is adequate to meet the needs of fusion reactors. Moreover, large superconducting TF coils have been developed for the large coil test facility. Coils with fields up to 15T are being developed.

Testing in non-fusion facilities includes:

(i) Blanket technology

Blanket is an important component which simultaneously provides the functions of energy conversion and recovery, fuel (tritium) breeding and partial shielding. At the same time it is exposed to a high heat flux, severe radiation loads (fast neutrons) and high magnetic field. Blanket is divided into solid (Li and some of its alloys) and liquid (Li_2O and flibes). each type has its disadvantages. The most serious uncertainties of a solid breeder blanket are related to the tritium breeding, tritium recovery and the breeder thermomechanical behaviour. Whereas, some of the largest uncertainties for liquid blankets are related to the hydrodynamic effects. The fluid flow, pressure drop, heat t[illegible], mass transfer and structural mat-

erials are all influenced by the magnetic field. In addition, the choice of a neutron multiplier is still under research.

(ii) Radiation Shield

The most critical issue of the radiation shield is the protection of superconducting magnets, vacuum equipment, plasma heating system, fast neutrons control system and plasma diagnostic systems.

(iii) Tritium processing and extraction system

The integration of the tritium systems or interfaces between the tritium systems and other systems is a critical issue. This is related to tritium monitoring and impurity removal. The extraction of tritium from the breeder depends on the fluid used to transport tritium from the breeder (LiPb, Li, He).

(iv) Plasma interactive components

The particular concern here is the control of impurities and exhaust system and also the in-vessel elements of the plasma heating and fueling system.

The test in fusion facilities requires an integrated test with complete components in the fusion environment to establish issues such as failure modes and reliability.

The requirements are shown in Table 2. [9]

Table 2

Requirements for Fusion Integrated Testing

Parameter	Reference Reactor	Test facility Parameter	
		Minimum	Desirable
Neutron wall load (Mw/m^2)	5	1	2 - 3
Surface heat load, Mw/m^2	1	0.2	0.2 - 0.5
Fluence, Mw/year m^2	15 - 20	1-2	3 - 6
Test port size (m^2 x m deep)	-	0.5 x 0.3	1 x 0.5
Total test surface area, m^2	-	5	10 - 20
Plasma burn time (s)	continuous	500	1000
Plasma dwell time (s)	None	100	50
Continuous operating time	Months	Days	Weeks
Availability, %	70	20	30 - 50
Magnetic field strength	7	1	3

5. CONCLUSION

In summary we can say that the final scientific stage will be reached by the year 2000 and a self-sustained thermonuclear reaction will be demonstrated, but this can only be accomplished by joint international efforts like that in ITER (International Tokamak Experimental Reactor) programme. By the beginning of next century, thermonuclear energy will be available and

different types of reactors will be developed to generate energy.

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SECTION XVII

BIOMASS, HYDROGEN, GEOTHERMAL AND WAVES

HYBRID INSTALLATIONS : AN ALTERNATIVE TO STORAGE AND AUTONOMY PROBLEMS.

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ABSTRACT

The idea of hybrid systems for isolated sites (wind-solar-Diesel) to generate electricity has been raised to solve autonomy and storage problems encountered with systems using one renewable source (eg: solar or wind). Also, it minimises investment and maintenance costs on the overall installation and particularly storage.

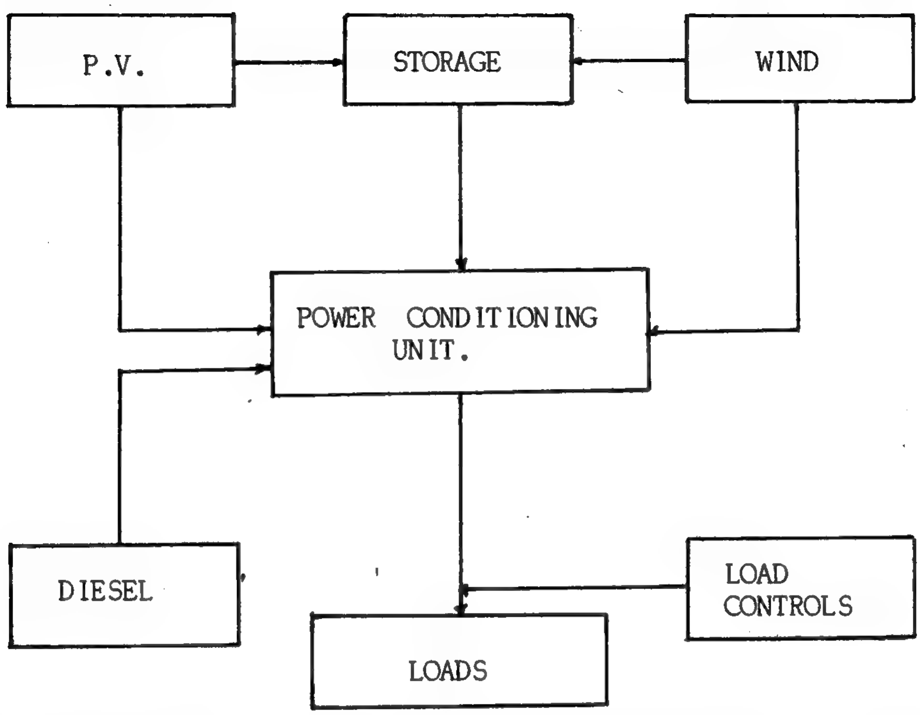
This paper describes the design of a pilot hybrid installation.
The methodology followed concerns :
- Analysis of solar and wind data to evaluate the energy potential available in the chosen site.
- Definition of the load from information contained in a survey destinated to rural users.
- Development of models to dimension the installation.
- Flow chart of a computer program developed to simulate the economic and operational optimisation of a hybrid installation.

1. INTRODUCTION

A particular attention has recently been given to the development of hybrid systems to garantee continous supply of energy to consumers when an alternative source is lacking.
This option is destinated to rural users of Algeria where the utilisation of Diesel generators is frequent and due to numerous problems of fuel transport and maintenance,the supply of energy is irregular causing enormous socio-economical problems to rural population.
The hybrid system designed is an experimental pilot project composed of a wind turbine, PV array, battery storage and an auxillary Diesel generator.

Design and testing procedure are described in this paper together with the knowledge of available energy potential (wind and solar) within the experimental site and typical load profile of rural user in Algeria obtained from a field survey.

2. DESIGN CONFIGURATION



WECS and PV provide the energy needed to consumers via a storage unit. The installation is dimensioned given load and potential data hence determining the contribution by each energy source (ie wind and solar). Power conditioning unit would be regulators to protect storage from over-charging or discharching and converter to provide the necessary current to consumer (ie DC or AC).
When discharge level is reached, Diesel generator is ON to provide the peak load conditions only, so that damage to the generator is avoided hence minimising the number of starts and stops to increase its operational life.

3. THE HYBRID PILOT INSTALLATION

Being a pilot project in a test site, the load chosen was primarly destinated towards the equipement and sensors installed needing electrical energy to operate. These are :
- Lighting and ventilation of mobile caravanes.
- Energy source to recorders and sensors.

Overall available load is as follows :

- AC load	: 1.6 kWh
- DC load	: 1.4 kWh
- Total load	: 3.0 kWh
- Dimensioning load	: 4.2 kWh
- DC voltage	: 24 V
- AC voltage	: 220 V
- Storage autonomy	: 350 Ah

Dimensioning the installation depends upon the energy potential available in the site and the performance of equipment used.
It is difficult to evaluate the energy potential available as it is site specific. However, data obtained from an automatic meteorlogical station

installed since Jan 1987 have given an estimation of wind and solar energy and have shown the intimate complementary nature of both sources.

3.1. Wind Potential

Data were obtained using an automatic station with 1 hour intervals from 1st February date of 1st operation.
Histograms of wind availability with seasonal influence are illustrated in Fig. 1 .
It shows that to optimise the operation of a wind energy converting system, its rated speed must match the mean wind speed in the site.
From Fig 1, it can be said that 80% of the time the wind has blown from 2.5 m/s to 3.5 m/s, hence orienting our choice of a WECS with a rated speed usually 1.5 * Vmean.
The average wind energy potential varies from season to another and lying between 500 Wh/m to 900 Wh/m (see Fig 2).
If the magnitude of wind speed is important, its variation is as valuable bringing us to say that the quality of data depe-nds on how variable the wind is.From statistics analysis,it has been concluded that with the site chosen the coefficient of variation was not high with the season of autumn showing the lowest value 11%.

3.2 Solar Potential

Considering the period of year of minimum sunshine (February), the PV energy production can be estimated and its contribution to satisfy the load deduced.The solar potential is measured by the same automatical station.Data of February 1987 were considered to dimension the PV array. They concern global radiation at local latitude ($+35^\circ$ $+10^\circ$).
The daily global radiation over the period chosen was found to be 4100 Wh/m^2.
As a comparaison between both potentials (wind and solar), it can be said that contribution from wind energy to the overall need can be of 25%.
Fig 2 shows the availability of wind energy / season as compared to solar energy. This way load to satisfy can be managed to minimise size and investment on storage capacity.

3.3. Matching the Site Potential to Energy Systems

The potential being evaluated, energy systems can now be dimensioned. Looking at the load to satisfy in the case of the pilot project ie: 4.2 kWh, contribution by each source (wind and solar) is specified with 75% in the case of PV.Considering the PV array with module efficiency of 13% at ideal conditions and matching batteries to modules efficiency factor of 85%, electrical energy produced by PV is estimated as 453 Wh/m^2.
With WECS,the overall conversion efficiency can be approx 20% for electrical applications with an optimum power coefficient of commercial WECS of 30% taking into account battery generator efficiency of 70% to 80%. The energy produced is estimated as 168 Wh/m^2. Refering to the proportion of energy produced by each source (75% for PV 25% for WECS),one can now determine the physical size of the hybrid installation.
Required diametre of WECS is 3m and number of modules 24(with 100mm dia cell and 36 cells/module) installed over an area of 6.6 m^2.

4. TEST PROGRAMME AND PROCEDURE

To evaluate and collect maximum information on this pilot project, continous measurement of essential parameters as energy produced by each

source, energy consumed, rotational speed of WECS, number of starts and stops of Diesel generator, duration of operation of energy systems, temperature of cells etc..are programed. Parallely to this, meteorlogical stations installed in the site collect permanently eight climatological data.

-Data to be measured :

-PV output current
-Diesel output current
-DC energy to consumer
-Battery input current
-Battery voltage
-Duration of operation
-PV inclined angle glob. rad.
-Yaw angle of WECS
-Cells temperature
-Relative humidity
-WECS output current
-Converter input current
-AC energy to consumer
-Battery output current
-PV voltage
-Horizontal global radiation
-Rotational speed of WECS
-Battery temperature
- Ambient temperature
-Wind speed and direction

5. EXEMPLE OF RURAL PROFILE IN ALGERIA

Although it is a pilot project located in a coastal region, a survey to evaluate the average load profile of a rural user was necessary. It allows the identification of load priorities and hence to perform an optimal size of storage. This survey concerns two villages, one situated in a coastal region and the other in a mountainous region.
Load profiles were almost the same for both cases with higher consumption in the case of Tirmitine village, (see Fig.3-4).
This can be explained by the fact that high energy use is related to climat and financial means of consumers. Peak consumption occurs between 19.00 and 23.00 hrs. Overall load lies between 4kWh to 5kWh / day with constant use of this energy over 75% of the day at approx 2kWh.
The trategy to follow in the case of hybrid installations in Algeria is to garantee energy from PV with WECS serving as a backup fed towards storage . Diesel will operate in emergency and under peak conditions only.

6. HYBRID COMPUTER SIMULATION FLOW CHART

A flow chart of a computer program simulating the operational conditions of a hybrid system is given in Fig 5 .
An autonomy storage capacity is given as an initial input specifying minimum charge level allowed usually 70% of the total capacity.
Time steps are chosen depending on the case but normally hourly values over a typical day are used. Energy potential data for the corresponding hour are fed together with the equivalent load data information which are taken from the load profile of the social survey.
Initial choice of energy systems are made depending on the availability of equipment and energy potential data. Energy produced from both sources is computed and net energy obtained (difference between energy demand and energy produced). This value is then tested to see whether the demand is satisfied or not at that hour of the day.
3 conditions can be met. The load is satisfied, therefore there is an excess of energy which is fed towards an auxillary load or battery storage if it's not fully charged. The load is not satisfied, in this case either the energy demand doesn't exceed the state of charge of batteries, and therefore part of the stored energy is used with the remaining fed as an initial state of charge, or the energy demand exceed the capacity of batteries which is in the case when the Diesel generator is switched ON operating under peak

condition only. Number of starts and stops can then be computed to see whether Diesel intervention is important or not.
Energy demand against energy produced pattern can be plotted over the whole day to see the behaviour of various components of the installation.
An economical analysis of the whole system can then be made to compare with autonomous PV or Diesel generators. Deciding upon the final choice of battery capacity and energy equipment will depend upon how good the energy pattern would look.

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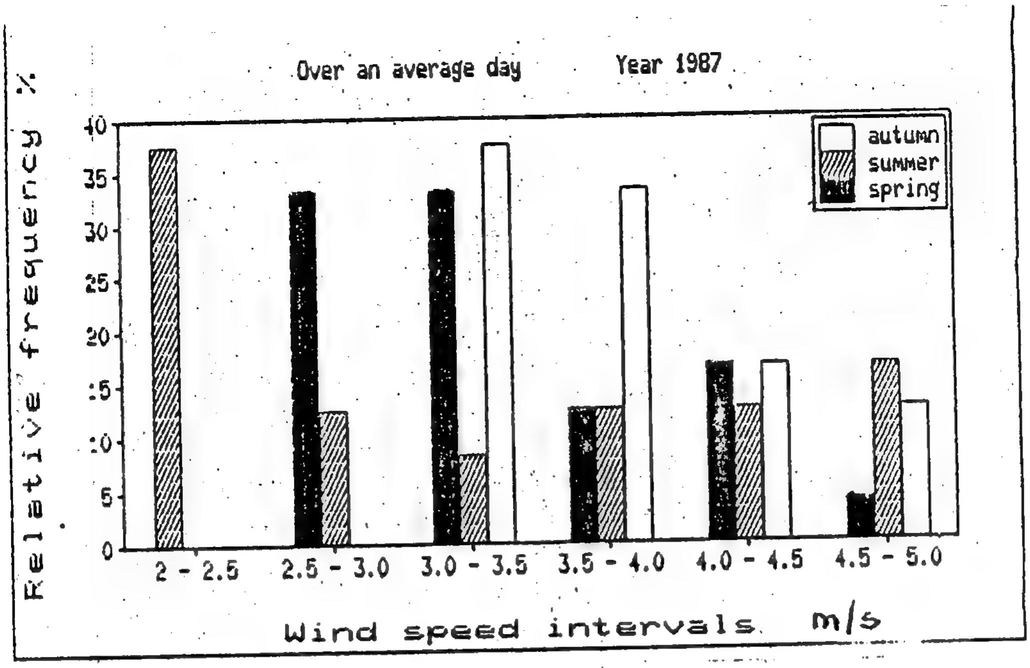

Fig.1 : Seasonal relative frequency at site of Bou-Ismail.

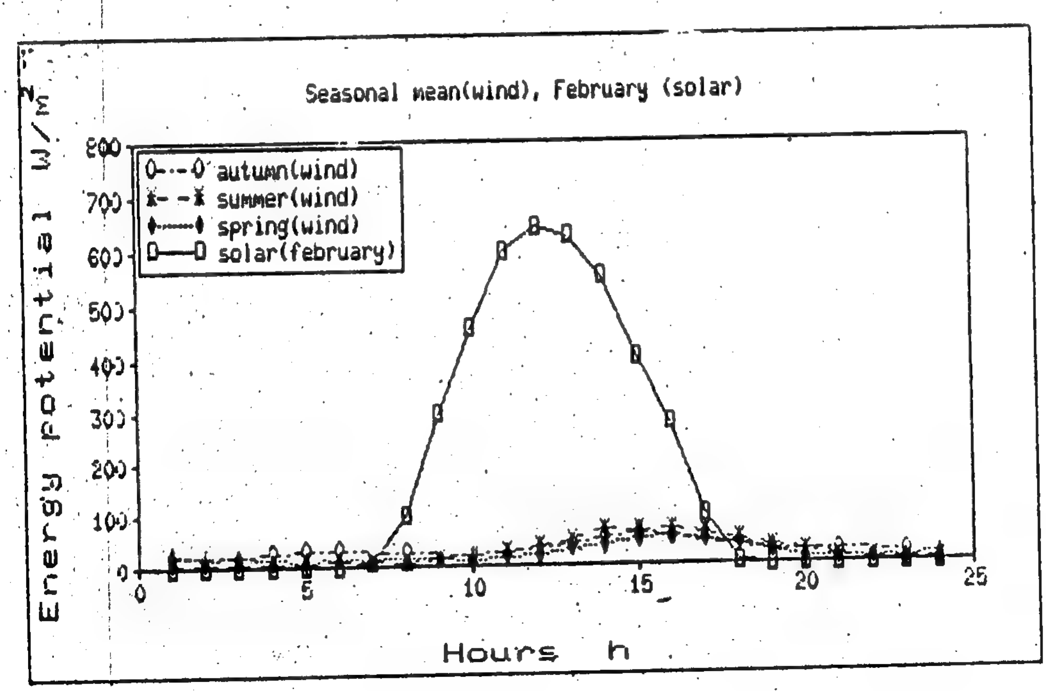

Fig.2 : Available Energy potential at site of Bou-Ismail.

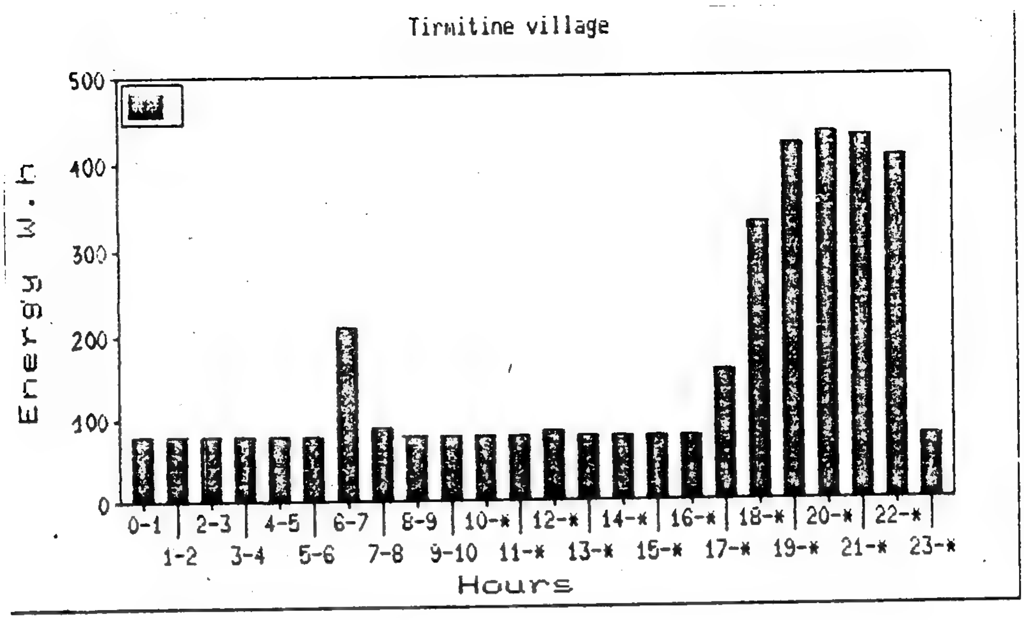

Fig: 3 : Hourly consumption

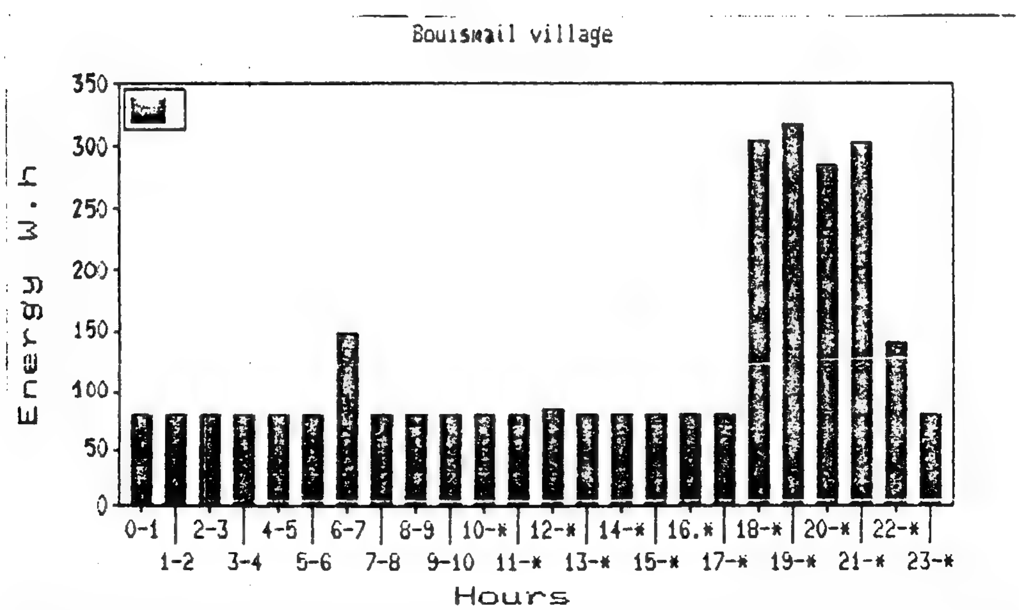

Fig: 4 : Hourly consumption.

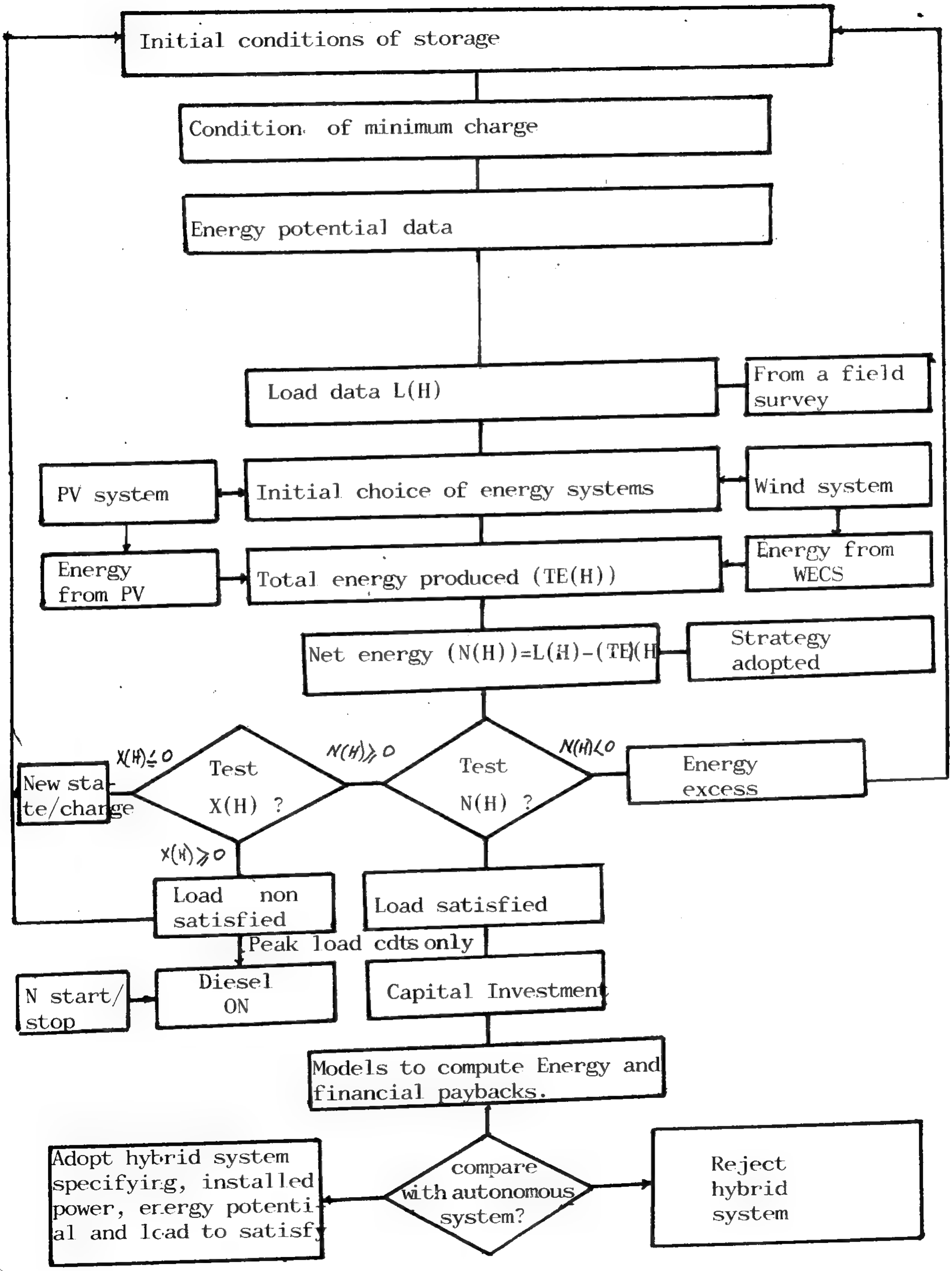

Fig.5 : Hybrid computer simulation flow chart

"OPTIMUM BIOGAS GENERATION: AN EXPERIMENTAL STUDY"

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1. ABSTRACT:

Bio gas generation is an anaerobic decomposition process which is carried out by various types of acid and methane forming bacterias. Activities of these bacterias mainly depend on physical, chemical parameters and bacterial activities. The envionmental conditions suitable for survival of different types of bacterias are also different. Generation of gas is affected by methane forming bacterias due to its susceptible nature. There are many reasons which restrict the popularisation of use of Bio gas in rural areas of our country. The rate of gas generation is very slow which requires large digesters. The cost of gas generation/ m^3 volume of plant is very high. Various research workers working in this area have suggested various methods for improving gas generation such as addition of nutrients, use of methane forming micro organism as inoculum, recycling of effluents, use of filters, use of separate digesters. Requirement of large quantity of water for mixing, drying and handling of effluents are some of the major problems.

In the present work study of single stage and two stage digester with and without filter, have been conducted to see the effect on rate of gas generation, total gas generation and quality of gas generated. The data obtained from this experimental set up has been analysed and results are discussed.

2. INTRODUCTION:

In actual bio gas plant the rate of gas generation is very low. Some of the factors [1] due to which gas generation is low are, given below:

(i) Percentage of nitrogen in influent is very low which is not capable of producing much daughter cells[2]

(ii) Washout decreases the number of methane forming bacterias.

(iii) Number of methane forming bacterias are very less as compared to acid forming bacterias.

(iv) Rehabilitation problem increases unstability and uneven gas generation.

(v) Leakage of gas through inlet and out let.

(vi) High quantity of water requirement and sludge handling.

3. DESIGN CONSIDERATION:

Experiment conducted by Srivastava D.N. and Gupta B.D.[3] indicates that recycling of effluent upto 30% can solve the problem of less number of methane forming bacteria as well as increases the percentage of nitrogen which is suitable for producing more daughter cells. Washout of the bacteria can be minimised by recycling as well as by changing the mode of feeding from daily to weekly. Experiments conducted by James C. Young [4] and C. Venkobachar etal[5] indicates that various types of filters and flow system, can minimize the problem of rehabilitation. Physical and Chemical parameters can be controlled by using two separate digester as suggested by Roy D. and Jones L.M.[6] .

4. EXPERIMENTAL SET UP:

A detention period of 15 days was taken based on the experimental results obtained by Srivastava D.N. and Gupta B.D. [7] . These results are reproduced in figure[1] Based on above consideration three set of experiments were carried out with single stage and two double stage digesters as shown in figure-[2] Digester for these experiment taken are of 3.5 litre capacity. Weekly feed was given from the top of primary digester of each set as suggested by Dreste R.L[8] One of the secondary digester had a filter in second stage digester. After first week of experiment 50% of the effluent was withdrawn from the middle zone of primary and secondary digesters by a pump. Fresh feed alongwith effluent was fed in suitable proportion into the digesters. Feed composition is decided as suggested by Srivastava D.N. and Gupta B.D[9] and given in Table[1] . Rate of gas generation was recorded on daily basis while pH value, composition of the gas, Total solid content were estimated on weekly basis.

TABLE: 1 Feed Composition

Sample - 1. Gobar 100%, Water 100%
Sample - 2. Gobar 90%, Slurry 10%, Water 100%.
Sample - 3. Gobar 80% Slurry 20%, Water 100%.
Sample - 4. Gobar 70%, Slurry 30%, Water 100%.
Sample - 5. Gobar 60%, Slurry 40%, Water 100%.
Sample - 6. Gobar 50%, Slurry 50%, Water 100%.

Table: 2 Gas Generation in Litre/day/kg. of weekly feed

S.No.	Day No.	Gas generation in litre					Remark
		Single stage	Two stage without filter		Two stage with filter in		
			Primary	Secondary	Primary	Secondary	
1.	8th	2.59	3.62	1.41	3.22	1.83	
2.	9th	3.30	7.62	1.65	3.71	1.08	
3.	10th	3.73	6.40	1.33	4.00	1.33	
4.	11th	3.92	5.33	1.33	4.00	1.33	
5.	12th	5.43	7.42	1.35	4.95	1.13	
6.	13th	6.00	5.60	1.20	5.20	1.20	
7.	14th	5.67	6.60	1.40	5.67	1.33	
8.	15th	6.00	6.63	2.47	6.10	2.53	
9.	16th	6.53	6.86	2.00	6.39	1.83	Max. Temp. 36°C
10.	17th	6.70	6.83	1.93	6.70	1.33	
11.	18th	5.50	4.77	1.63	5.16	1.47	
12.	19th	3.17	3.00	1.00	3.10	0.93	
13.	20th	3.47	3.54	1.50	3.76	1.67	Max. Temp. 30°C.
14.	21st	3.80	4.23	1.13	3.73	1.67	
15.	22nd	4.47	5.63	2.33	4.58	2.50	
16.	23rd	6.13	6.17	1.93	5.90	2.43	
17.	24th	5.03	5.09	1.73	5.07	1.76	

RESULT AND DISCUSSION:

1. During the experiment a temperature variation of 6° to 7°C was recorded, while gas generation had gone up by 50%.

2. In double stage digester, the rate of gas generation had been obtained for weekly feed as 9.27 litre/day, while in single stage it is found 6.70 litre/day. This shows an increase of gas generation by 20% in double stage digester as compared to that in single stage.

3. Carbon dioxide percentage was measured by Orsat apparatus and it was found to vary between 16% to 20% in the biogas from primary digester and less than 10% from secondary digester.

4. The pH value of effluent from secondary digester was found to be approx. 7.5 while pH of effluent of primary digester was 6.8. The increased value of pH in secondary is suitable for methane forming bacteria.

5. In primary digester, the gas generation takes place in the upper half portion, while in secondary it takes place in lower half. There is no scum formation in the secondary digester.

6. Coal filter in secondary digester does not found to be effective in increasing the gas generation.

7. Effluent of secondary contains only 2% solid content and this effluent can directly be used for irrigation purpose because of low solid content.

8. Due to reduced detention period, the plant size can be significantly decreased.

9. The scum will not get dried because of the movement of the upper layer during feeding from the top and bubbling of the gas.

10. It has been observed that bacteria develops more in secondary digester. Feed in secondary digester may increase the rate of gas generation and this may lead to effective use of secondary digester.

11. Left over solid portion of the feed can be withdrawn from the bottom of the digester.

FUTURE WORK:

Effect of suitable filter in primary digester on gas generation is to be studied in a two stage digester system. Suitable design of two stage digester based on above observation has to be produced and prototype may be fabricated. Experiment has to be carried out on this prototype. A design is to be recommended for use based on the inference drawn from the above experiment.

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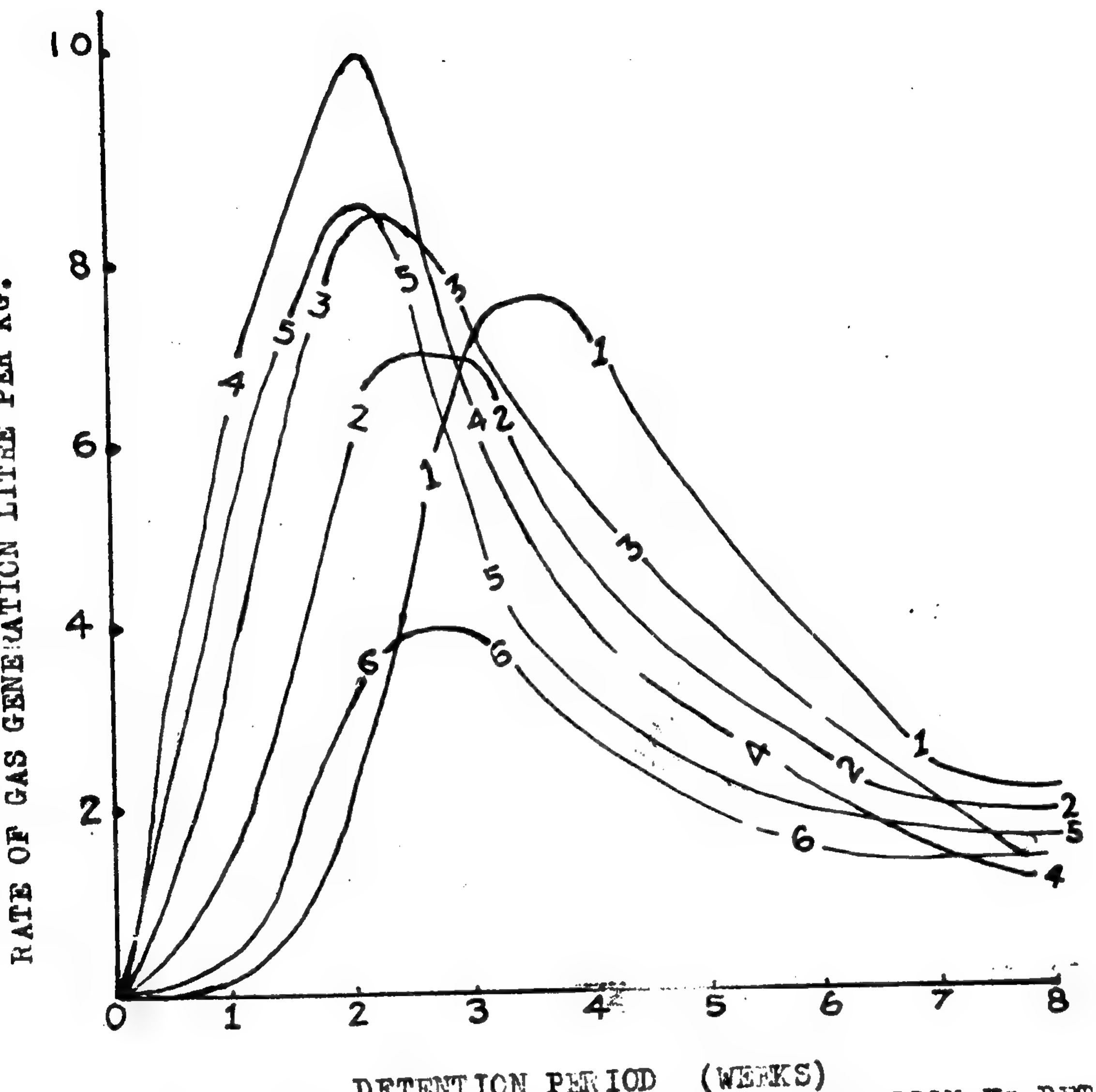

FIG. 1 GRAPH BETWEEN RATE OF GAS GENERATION Vs DETENTION PERIOD

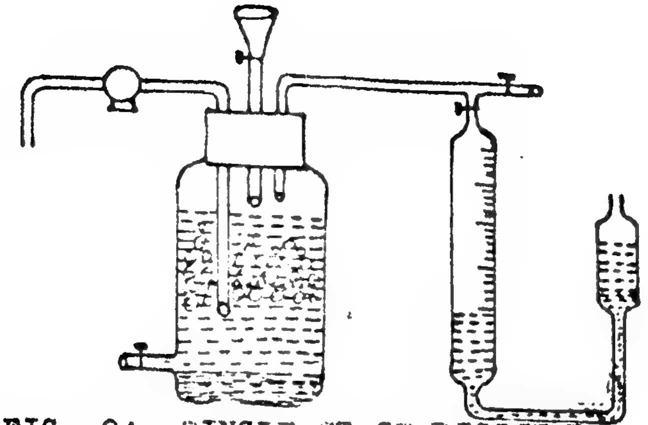

FIG. 2A SINGLE STAGE DIGESTER

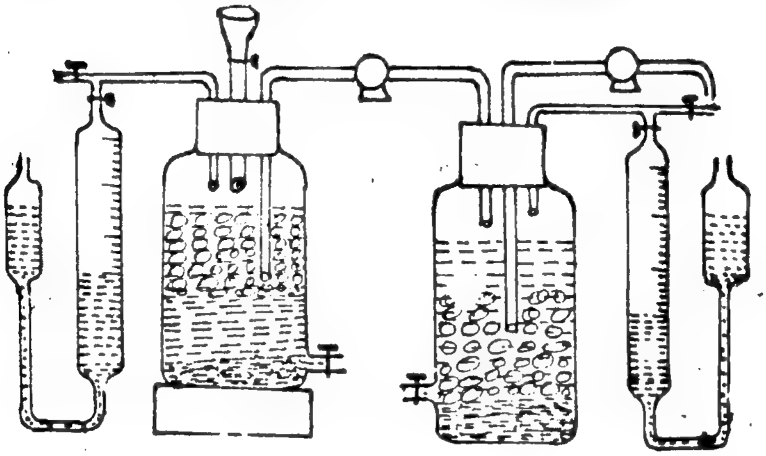

FIG. 2B TWO STAGE DIGESTER (WITHOUT FILTER)

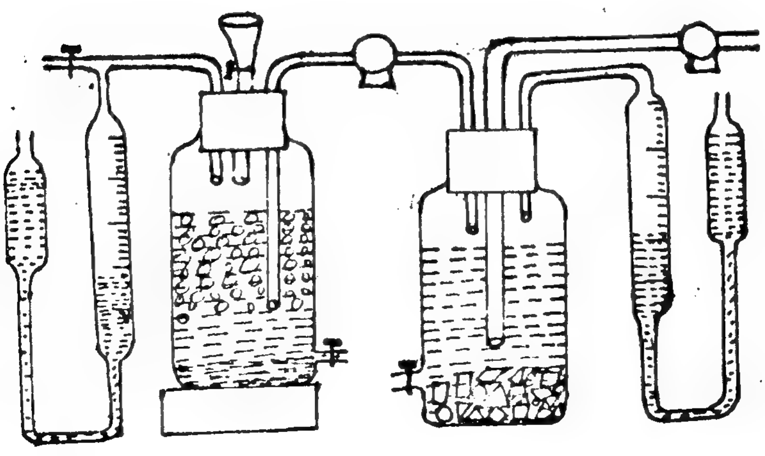

FIG. (2C TWO STAGE DIGESTER (WITH FILTER)

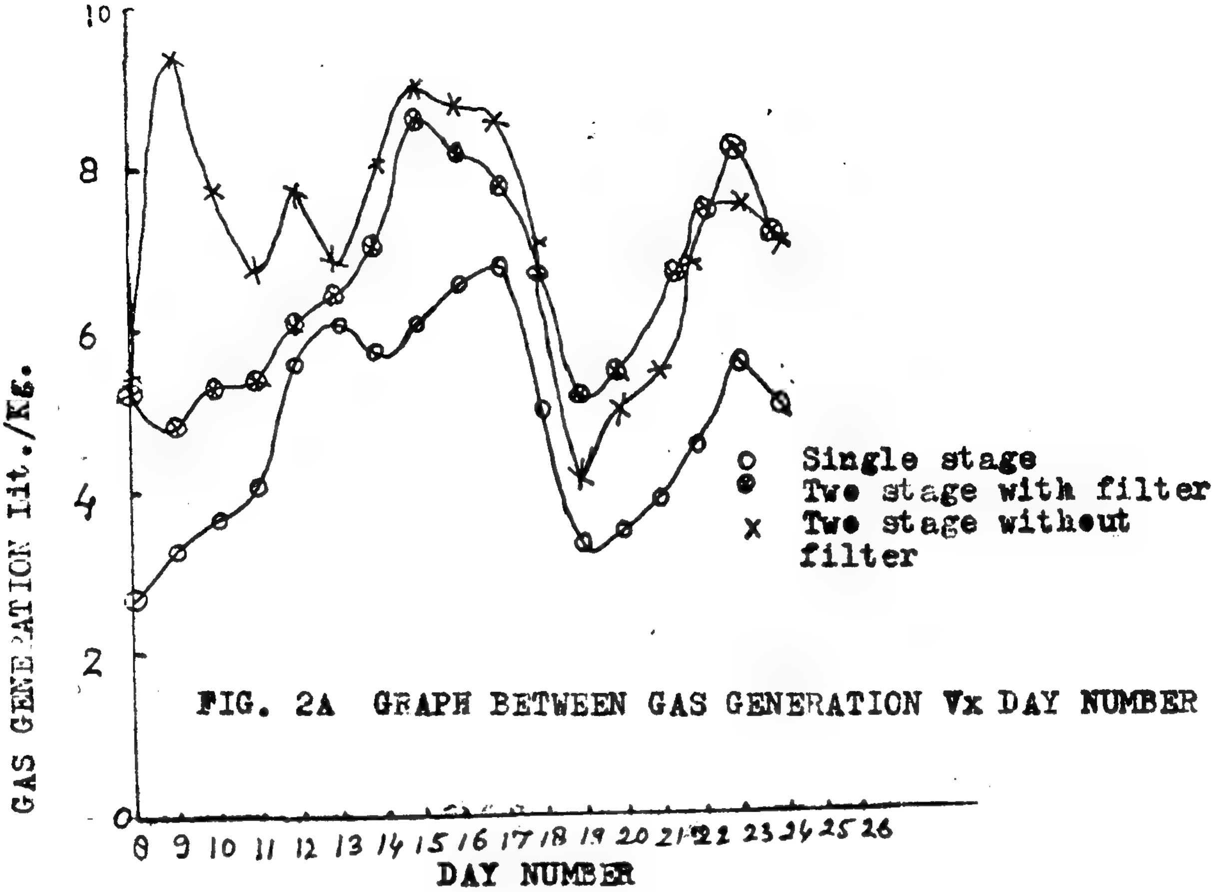

FIG. 2A GRAPH BETWEEN GAS GENERATION Vx DAY NUMBER

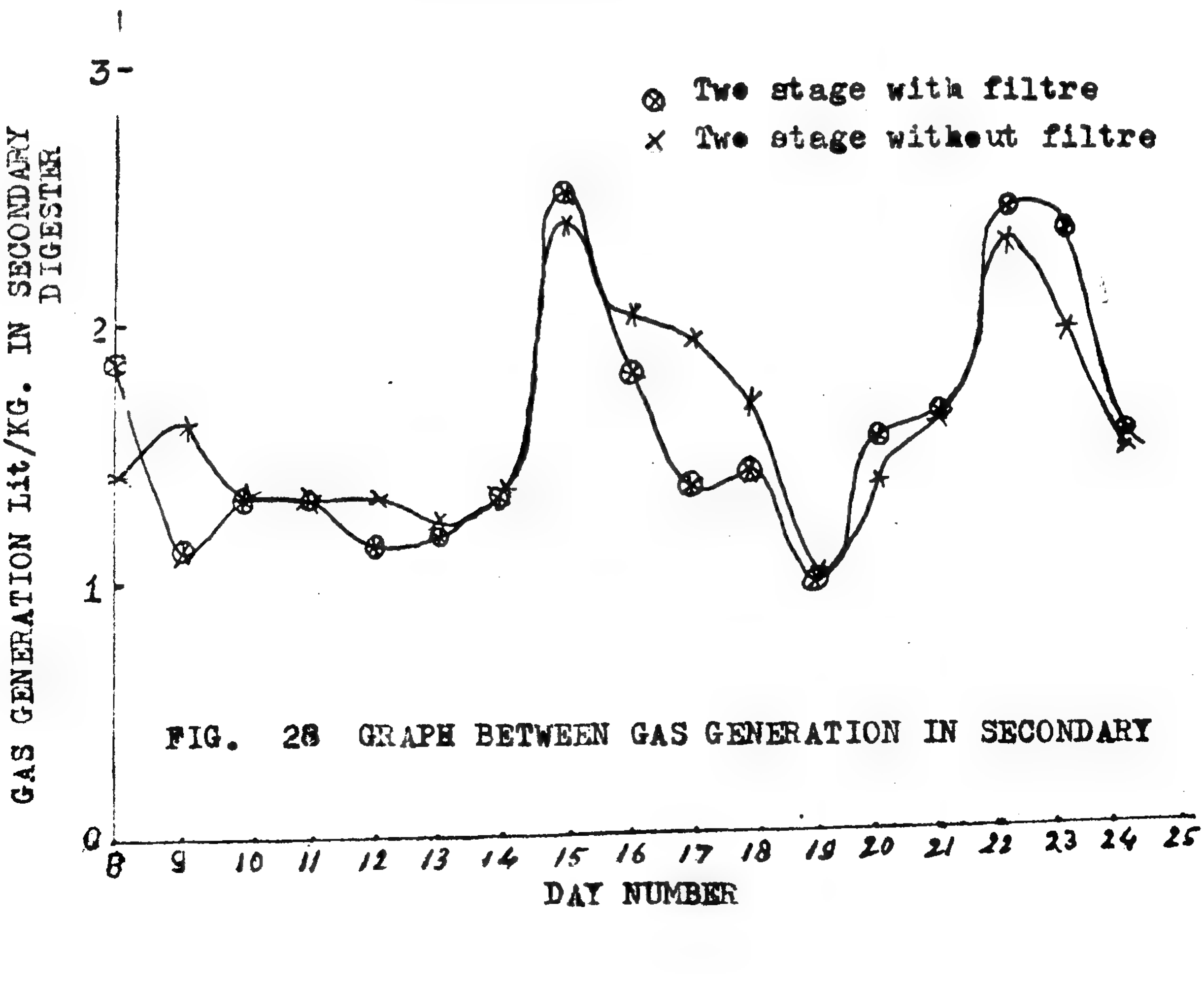

FIG. 2B GRAPH BETWEEN GAS GENERATION IN SECONDARY

RELIABILITY OF HYDROGEN FOR USE IN TRANSPORTATION

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ABSTRACT

This paper investigates the possibility of using hydrogen as a replacement for hydrocarbon fuels in the transportation sector. The system conversion problems alongwith their current solutions were explored. Both safety and hazards of hydrogen fuel were discussed and has concluded that hydrogen, as any fuel, is safe if the necessary precautions are taken. Refuelling and fuel feeding system are suggested taken in consideration the benefit of closing loop technique. This study showed the practicality of liquid hydrogen in the transportation sector with the available technology for both handling equipments and engine modifications. A preliminary study for using the liquid hydrogen in transportation sector in Jamahiriya was included with recommendation for a detailed study to determine the number of production plants, services stations and the economic evaluation alongwith the conversion program.

1. INTRODUCTION:

Currently, hydrogen, in both liquid and gas forms, has a wide use in the industry and in the space transportation. In the industry, it is used in manufacturing of many chemicals, such as in the synthesis of ammonia, and the utilization of liquid hydrogen in the space program has led to the transportation of large payload into the orbit. Many researches have been conducted during the last fifteen years to study the possibility of the utilization of liquid hydrogen in the most of the transportation sectors. This is because the transportation sectors account for more than one half of the world oil consumption, and because of the predicted shortage in the hydrocarbon fuels.

The high energy content and the minimal environmental impact of liquid hydrogen have given it a great potential as an aviation fuel. A study sponsored by NASA revealed that

hydrogen fueled subsonic aircraft is superior to jet - A fueled aircraft in all respects except that the space required for storing hydrogen may make the airplane a little longer [1]. Also, the large heat sink of hydrogen fuel is so important for hypersonic flight and makes only hydrogen practical future fuel for very high speed aircraft.

Now, it is becoming more and more apparent that the conversion of automobile gasoline engine to hydrogen engine is possible. Many investigators have indicated that the conventional internal combustion engine, with minor modification, can operate with hydrogen as a fuel, and the only problem is the Technology of fuel tanks. An investigastion conducted by U.S. Department of energy joined with other institutes on a 1979 Buick Century has shown that liquid hydrogen is a practical alternative fuel for transportation [2]. Another extensive research program was carried out by several companies and institutes in Garmany and technically coordinated by Mercedes Benz Berlin branch concluded that the available technology for hydrogen storage, refuelling stations and engine fuel systems have demonstrated very good performance [3].

2. The Hydrogen:

With the available technology the hydrogen can be produced by many techniques such as by chemical reactions, electrolysis and thermochemical decomposition of water. Splitting of water to hydrogen has received much attention than the other techniques. Using heat from large nuclear reactor for thermochemical water splitting could produce low cost hydrogen [4]. The main hydrogen representive properties that characterize the use of hydrogen as fuel for transportation are displayed in the following table.

Property	Value	Units	Property	Value	Units
Density (0^oC)	0.0899	g/l	Molecular Weight	2.016	amu
Vaporization rate	2.5-5	cm/min	Viscosity (20^oC)	87.6	poise
Quenching gap in STD Air	0.64	mm	Boiling Point	20.3	K^o
Min.energy for ignition in air	20	KJ	Heat of fusion	58.23	J/g
Auto Ignition temp	858	K	Heat of vaporization	445.6	J/g
Diffusion coeff. in STD air	0.61	cm^2/se	Flamability in air % vol.	4.0	74.2
Burning velocity in STD air	865-325	cm/sec	Detonability in air % vol	18.3	54
Velocity of sound	1284	m/se			

STD = Standard day, Vol. = Volume

The low density of hydrogen makes its use as a gas in the transportation sectors is obsolete, due to the large volume required. A volume of 4.1 liters of gasoline correspond to 12350 liters of hydrogen gas on equivalent energy bases. This large volume can be reduced to 30 liters if the gas is pressurized to 400 atmospheres. Also, this volume may be reduced using liquification or metallic hybride techniques.

3. Some Technical Problems:

The very low level of minimum ignition energy and quenching distance help largely to cause backfiring, preignition and spark knock, in the same time the flame speed and the wide range of flammability have their contribution to these problems. The high diffusivity of hydrogen may cause the unburned fuel to escape to the crank-case through the piston rings. Also, the high combustion velocity of hydrogen alongwith long ignition delay may lead to hot gas vibration in the cylinders [5] . Reference [6] withdrawn from his experimental investigation that the problem of backfire can be eliminated by direct cylinder injection method. In this method, the hydrogen is injected during the first half of compression stroke and ignited by spark plug. Also, he indicated that cold hydrogen supply to the engine is necessary in order to prevent preignition at high load. This conclusion was also shared by Reference [7], and in which he reported that turbocharging the hydrogen to the engine could provide higher output power than the corresponding gasoline engine.

4. Handling and Safety:

Many investigators have preferred liquid hydrogen over compressed gas or metallic hybrides in automobile applications. This because the heavy weight of the hybride system and the refuelling time required, and the very high pressure involved in the pressurized system in addition to the energy required for the both cases. The cost of hydrogen liquification is strongly function of the technology used to produce it and the quantities in which it is used. The liquification of hydrogen may be achieved by precooling it below 205 K using liquid nitrogen and subsequent expansion will incur a further decrease in temperature to the hydrogen boiling point.

The low temperature of hydrogen liquid will not cause problem to the handling equipments because a number of common aluminium alloys, low carbon steel and stainless steels have adequate ductility at this temperature. Also, the available insulation materials and technology have guaranteed minimum boil off of hydrogen in both the refuelling and automobile tanks.

Even liquid hydrogen has some hazards, it has several safety advantages. The low molecular weight and small molecular size of hydrogen make it to break easier and spread faster than other gases, however, its high diffusivity makes it to dissipate faster and thus less damage when accident to occur. The high ignition temperature of hydrogen makes the hydrogen

air mixture ignites only by an open flame, in the same time it is not explosive under unconfined conditions. In general, a proper safety comparison of hydrogen and other fuels is difficult because of the many variables involved in the physical property of the fuels, but to date liquid hydrogen has good safety record especially, in the airspace applications.

5. Suggested Fuel Flow and Refuelling Systems:

By the nature of hydrogen fuel tank design, it is more difficult to rupture than a conventional gasoline tank. To increase the safety consideration, the tank is located in the trunk far from the most common place for automobile collisions, and the passanger compartment is protected from splashing by light weight screen. The feeding system is suggested as shown in Fig. 1.

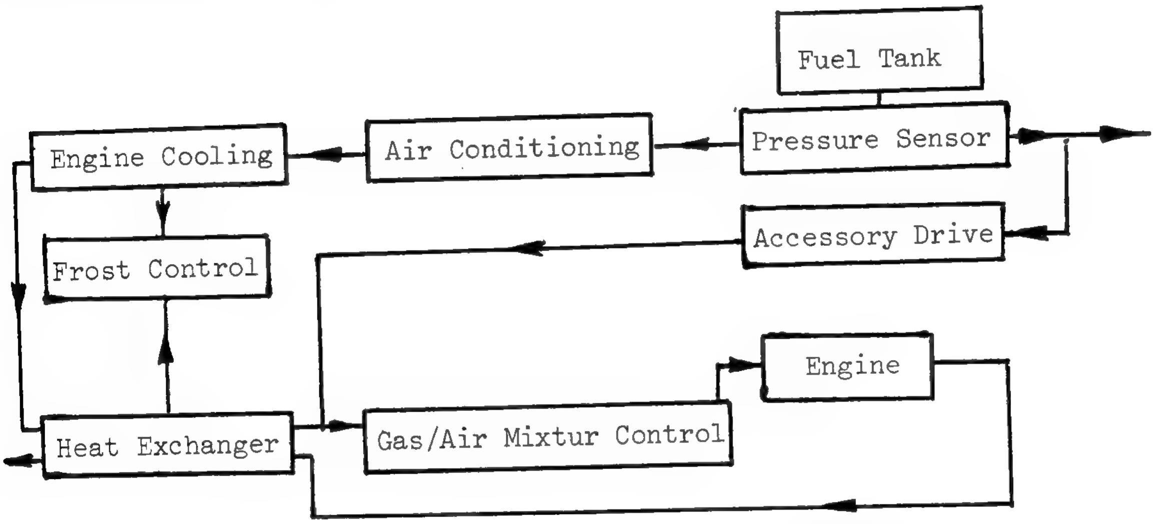

Figure 1 : Fuel Feeding System

In this arrangement, the pressure sensor controls the ventilation rate and permits the fuel flow according to downstream pressure change. Also, it terminates the flow in case of excessive leakage due to mallfunction of any system or an accident. The passenger compartement temperature is controlled by the air conditioning unit. The accessory drive unit makes use of boiled off hydrogen alongwith the hydrogen gas to power the steering system, hydraulic system, etc. The frost build up during the heat exchange in the engine coolent unit and in the heat exchanger is controlled by the frost control unit.

More safety consideration should be also given to the refuelling stations . As new system to the user, a human errors may occur and to eliminate these errors a fully automated refuelling system is suggested in the first years of service. Also, the interface system between automobile and service station should be close system type as shown in Figure 2, to prevent vapor escaping during operation.

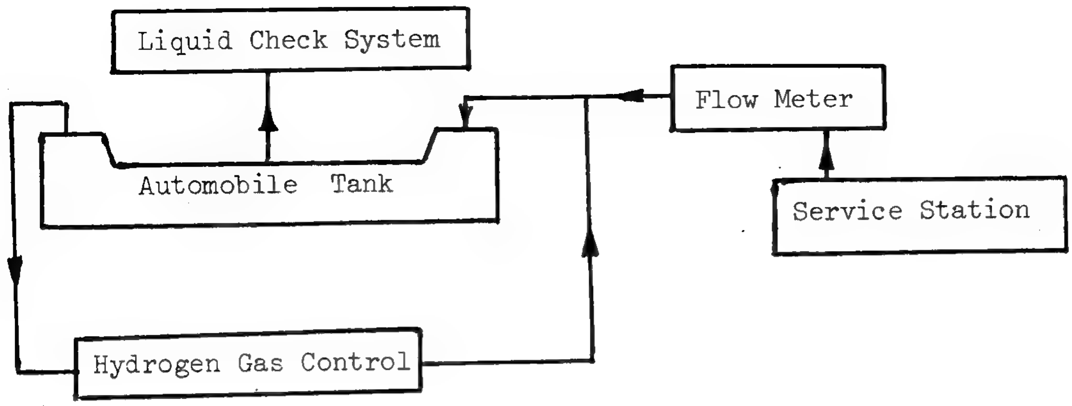

Figure 2 : Automobile-service station interface

In this system of interface the fuel supply valve is closed as soon as the liquid hydrogen starts passing the liquid check system and double checked by the flow meter. The hydrogen gas control system works in two ways: to supply hydrogen gas for draining and leak testing of supply lines and to monitor the boil off of liquid hydrogen during the refuelling. Generally an educational program is required for both the service station personnel and the general public.

6. <u>Introducing Liquid Hydrogen to Transportation in Jamahiriya</u>:

The economic aspects as well as the problem of conventional fuel shortage and its environmental; impact should both be studied in parallel when the liquid hydrogen is introduced to the transportation. Jamahiriya as oil produces the gasoline prices currently is attractive in comparison with hydrogen fuel. However with the expected increase in gasoline price and as the number of liquid hydrogen plants and users increase the cost of hydrogen fuel will be acceptable.

In Jamahiriya, the number of gasoline fueled cars on the road is about 500,000 cars with average travelling distance per year of about 18,000 km. These cars burn about 1.35 billion liters each year on the basis fuel consumption rate of 15 liter every 100 km. The conversion plane may start with 10% of these cars and in this case 135 million liters of gasoline can be saved for other uses. The corresponding hydrogen requirements is about 500 million liters in addition to the losses from boil off, transfer, cool-down, etc which is expected to be 8-14%. The engine modification may exceed 400 Libyan Dinars.

A detailed study to determine number of production plants and their places, service stations and delivery vehicles alongwith the conversion program is needed, and it is out of the scope of this paper.

7. Conclusions:

The available literature alongwith the material presented in this paper have shown the practicality of hydrogen liquid as replacement for hydrocarbon fuels in the transportation sector and the technology required for hydrogen fuelled engines development is essentially directly transfer from the currently engine technology. The handling equipments have been proved for use by many applicants. As the economy is concerned liquid hydrogen cast is strongly function of the technology involved in the production and the quantity used. Hydrogen as any fuel has some hazards, but it is a safe fuel when the necessary precautions are taken.

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THERMAL EFFICIENCY AND THERMODYNAMIC CYCLES OF GEOTHERMAL POWER PLANTS

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1. Introduction

The consumption of energy in the world will increase rapidly because of increasing the population and the new technological developments, Nowadays most of the energy consumed in the world is based on the utilization of fossil, hydrolic and nuclear energy. Oil crisis in 1974 gave a great impact to many countries, they were obliged to find out new energy resources substituting for petroleum and saving energy. That's why many investigations have been done on the new energy resources in many countries. Geothermal energy is one of very prospecting and attractive clean energy. However from the stand point of abundance, economy and reliability of natural resources, development of geothermal energy is of a great advantage.

Geothermal energy resources, which were being used more for the hot baths have begun to be used for electrical power generation widely recently. It was at Larderello in 1904 that prince piero Ginori Conti first harnessed the power of natural geothermal steam to produce electricity. After the world war II, the United States and New zealand challenged to the geothermal energy development and succeded in power generation at the Geysers and the Wairakei plant. The geothermal fields at Larderollo and the Geysers are dry steam resources, and as such are relatively easy to exploit as a source of electricpower. The vast majority of them are liquid dominated, that is, they yield a mixture of steam and hot water at the wellhead. At present the geothermal energy contributes about o,1 % in the world electric energy demand [1]. Devoloping status of geothermal power plants in the world is shown in Table 1.

Thermodynamic Cyeles of Geothermal Power Plants :

Geothermal power cycles can be classified according to the method of geothermal energy utilization. We can clas sify geothermal pwer generation cycles as shown in Figure 1 into three basic types.

a- Dry steam Power Cycle Type :

The most simple power economical geothermal power cycletype. Dry steam produced from geothermal field is fed directly through a pipline to a turbine. The steam that works at the turbine is exhausted to the condenser. The condensed steam is pumped from the condenser to the cooling tower by condensate pump. Cold water from the tower flows to the condenser. as cooling water. The power cylce as shown in Figure 1- a is an open cycle. This sort of power cycles are not extensive becouse dry steam geothermal fields are not much enough.

b- Flashed steam power cycle Type :

In the early 1960 's New Zealand pioneered the recovery and conversion of energy in hot-water deposits by using the so-called "flashed steam method". The wellhead product is fed into a flash separator where the vapor fraction is increased by an isenthalpic expansion to a low pressure. The steam is then used to drive a multistage steam turbine for electric power generation. Overall efficiency is increased by the use of condensing turbines where ever the proportion of noncondensible gases is sufficiently low. The hot water fraction separeted by the flasher is discarded as wasted energy. The overall thermal efficiency is low since, at best, only about 10 percent of the thermal energy at the wellhead is converted in a single-flash cycle, Figure 1-6 The efficiency can be increased somewhat , by using additional stages of separation,Double flash cycle, Figure 1-C, can produce 20 % more electric power compared to single flash at the some fluid condition with a slight increase of construction cost [1] At the time when this cycle is used, the change of steam/water ratio in the resorvoir under plant operating and the drop of water temperature are considered.Because that the geothermal field might not produce the hot water which is needed the cycle.

The flashed steam system is simple, it utilizes standard machinery, and is workable if the salinity of the water is low ($\leq$ 3 percent dissolved solids) since carryover of salts into the vapor can cause corrosion,erosion, or scaling of turbine compenents.

C- Binary Power Cycle Type :

Binary power cycle is useful for low grade geothermal energy resources produced below 100 C hot water, in order to isolate the turbine from corrosive or erosive materials and to accommodate higher concentrations of noncondensible gases; the binary cyle concept, is now receiving considerable attention as an alternate power cy le concept. This is basically a Rankine cycle with an organic working fluid. A heat exchanger is used to transfer the energy of hot water to vaporize the secondary working fluid. The working fluid. Expands through a turbine for electric power generation. It is condensed at condenser and recirculated continuously, Figure 1-d sofar, there is only one such operational geothermal binary cycle plant. It was installed in 1967 and is located on the kamchatka Peninsula in the USSR.

C- Thermal Calculations of Kızıldere Geothermal Power Plant :

The first Turkish geothermal power plant was installed at Denizli-Kızıldere in 1984, The plant capacity is 20 MW (Plant output is 17,8 MW). Figure 2 illustrates schematically the elements of the plant. Thermodynamic cycle of the plant is shown in figure 3. Technical characteristics of the plant are given in Table 2.

Table 2 : Specification of Kızıldere Geothermal Power Plant [2]

Wellhead :

Total : 9 wells

Pressure : 15 bar

Temperature : 205 °C

Steam fraction (weight) : % 10-11

Separator :

Pressure : 5 bar

Temperature : 148 °C

The Main Separator :

Pressure : 4,54 bar

Temperature : 147 °C

Turbine İnlet :

Pressure : 4,5 bar

Temperature : 147 °C

Steamflow : 174000 Kg/h

Turbine Outlet- Condenser Inlet :

Pressure : 0,1 bar

Temperature : 46 ^oC

Cooling Tower :

Water Temperature inlet : 38,6 ^oC

Water Temperature outlet: 29 ^oC

Gas Content (Weight) % :

Co_2 : 15 %

Water vapor : 85 %

Calculation of Thermal Efficiency of The Plant :

Because the working steam consist of CO_2 gas and water vapor, it must be calculated both enthalpies of CO_2 and water vapor at turbine inlet and turbine outlet. The following calculations are for 1 kg steam flow.

At Turbine Inlet :

$Pv = mRT = (m_w R_w + m_{co2} . R_{co_2}) T$

$p = 4,5$ bar

$T = 147+273=420\ ^oK$

$R_w = 461$ kj/kg^oK

$R_{co2} = 188$ kj/kg^oK

$4,5x10^5 . V = (0,85.461+0,15.188)\ 420$

$V = 0,4\ m^3/kg$

$P_{co2} . V = m_{co2} . R_{co2} . T$

$$P_{co2} = \frac{m_{co2} . R_{co2} . T}{V} = \frac{0,15.188.420}{0,4} = 29610\ N/m^2$$

$P_{co2} \cong 0,3$ bar

$P_w = P - P_{co2} = 4,5-0,3 = 4,2$ bar

$h_{co2} = C_{pco2} . T$

h_{co2} = enthalpy of CO2 gas (Kj/Kg)

C_{pco2} can be calculated the following equation suggested

by Wylen and sountag [3]

$C_{pco2} = -3,73557 + 30,529\ (\theta)^{0,5} - 4,1032\ (\theta) + 0,024198\ (\theta)^2 \ldots (1)$

$$Q = \frac{T+273}{100} \left(\frac{°K}{100} \right) \ldots\ldots \qquad (2)$$

From equations (1) and (2),

$C_{pco2} = 0{,}96.Kj/kg°K$, at turbine inlet

$C_{pco2} = 0{,}86.Kj/kg°K$, at turnibe outlet

$(h_{co2})_1 = C_{pco2} . T1 = 0{,}96 . 420 = 403{,}2$ Kj/kg, at turbine inlet

$(h_{co2})_2 = C_{pco2} . T2 = 0{,}86 . (46+273) = 274$ Kj/kg, at turbine outlet

$h_{w1} = 2743$ Kj/Kg enthalpy of water vapor, at 4,2 bar

$h_{w2} = 2170$ Kj/Kg enthalpy of water vapor, at 0,1 bar

$h_1 = 0{,}15(h_{co2})_1 + 0{,}85\ (h_{w1}) = 0{,}15(403{,}2) + 0{,}85\ (2743) = 2392$ Kj/Kg.

$h_2 = 0{,}15\ (h_{co2})_2 + 0{,}85\ (h_{w2}) = 0{,}15\ (274) + 0{,}85\ (2170) = 1885$ Kj/kg.

<u>Turbine Theoretical Thermal Efficiency (η') :</u>

$$\eta' = \frac{h_1 - h_2}{h_1 - h_6} = \frac{2392-1885}{2392-192} = 0{,}23$$

$\eta' = 23$ %

$h_6 = 192$ Kj/Kg, Condensed water enthalpy at 0,1 bar

<u>Overall Thermal Efficiency of the Plant (η_t) :</u>

Thermodynamic cycle of the plant is a single flash cycle type. Hot water seperated by separator is wasted in this cycle. In this way a substantial fraction of the available energy is dis carded in the separated liquid. Separated steam/water ratio, (X_3), at the separator is calculated according to Figure 3.

$h_2 = h_2' + x_2\ (h_2'' - h_2')$

$h_3 = h_3' + X_3\ (h_3'' - h_3')$

$h_2 = h_3$ (isenthalpic process at separator)

The utilizing of enthalpy chart, steam/ water ratio is,

$X_3 = 0{,}20$

$$\eta_t = \frac{X_3 (h_4 - h_5)\ \eta_i \cdot \eta_g}{h_2 - h_6}$$

$\eta_i = 0{,}80$, turbine efficiency (assumed)

$\eta_g = 0{,}98$, generator efficiency (assumed)

$h_2 = h_2' + X_2 (h_2'' - h') = 845 + 0{,}11\ (2792-845) = 1059$ Kj/Kg

h_2 = geothermal fluid enthalpy at 15 bar, at wellhead.

h_6 = 192 Kj/Kg

h_4 = 2392 Kj/Kg, steam (CO_2 + Water vapor) enthalpy at turbine, inlet

h_5 = 1885 Kj/Kg, steam (CO_2 + Water vapor) enthalpy at turbine outlet.

$$\eta_t = \frac{0{,}20\ (2392-1885)\ 0{,}80 \cdot 0{,}98}{1059-192} = 0{,}091$$

Overall thermal efficiency, $\eta_t = 9{,}1\ \%$

Specific Steam Consumption (Kg/Kwh), Be :

$$Be = \frac{3600}{(h_4-h_5)\ \eta_i \cdot \eta_g} = \frac{3600}{(2392-1885)(0{,}80)(0{,}98)} = 9{,}05$$

Be = 9,05 Kg/Kwh.

5- Conclusions :

At present the geothermal energy contributes about 0,1 % to the world electric demand. This contribution is negligibly small in Turkey. [4] Kızıldere gecthermal power plant has not been able to work infull capacity because silica scaling of wells causes decline of well capacity.

Thermal calculations done for Kızıldere Geothermal power plant are shown that thermal efficiency of turbine is 23 % and overall thermal efficiency of the plant is 9,1 % (approximately 9 %). The specific steam consumption of the plant is also 9,05 Kg/Kwh. When geothermal power plant is compared with steam power plant, features listed below can be explained for geothermal power plant.

1- Location of power plant site is restricted to some prospective area like volcanic zone, therefore plant site cannot be chosen voluntarily.

2- As no fuel is necessary, plant running cost is negligible small.

3- Unit capacity is limited to some extent, because pressure and temperature of geothermal steam are comparativelylow and size of turbine is limited by some economical design concept of manufacturer.

4- Power plant system is simple because of no fuel, no ash, no feed water and no boiler, there fore whole plant can be operated easily by one man or remote control system.

5- Geothermal steam contains considerable amount of non condensable gases which must be eliminated by large scale vacuum system.

6- Large cooling tower system is necessary, because sufficient cooling water is

hard to abtain in geothermal area.

7- Problem of public nuisan are compatively little because location of power plant is usually in isolated place from crowded cities and no dust is emitted from chimney .

6- References :

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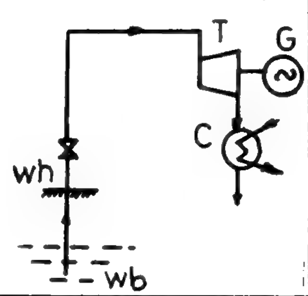
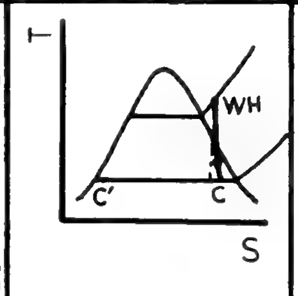
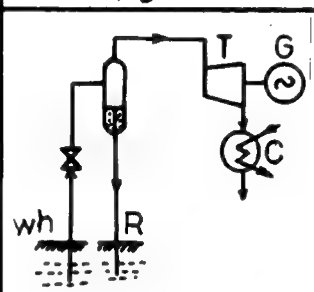
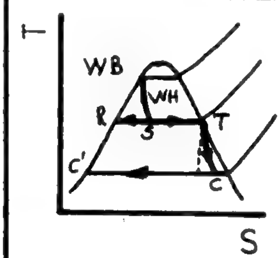
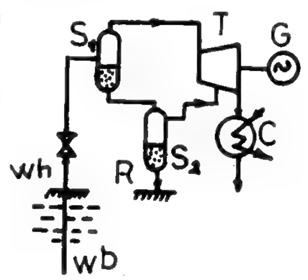
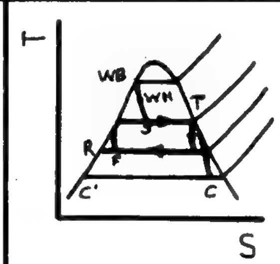
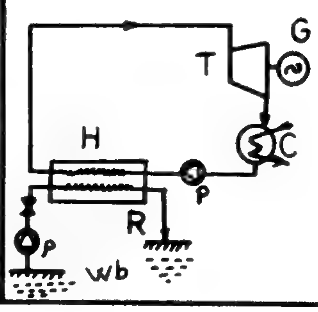
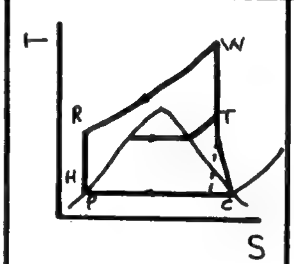
COUNTRY	GENERATING CAPACITY, (MW)	
	1984	Expected 1986
United States	1453,5	2256
Philippines	781	1496
Italy	472	502,1
Mexsico	425	645
Japan	215	270
New Zealand	167,2	167,2
El Salvador	95	95
Iceland	41	41
Niceragua	35	70
Indonesia	32,25	145,25
Kenya	30	45
Soviet Union	11	21
China	8,136	11,386
Portogal	3	3
Turkey	0,5	25,5
France	0	6
Totals	3769,686	5896,436

Table 1. Worldwide Geothermal Power Plants [1]

Figure 1. Geothermal Power Cycle Types

	The system	T-S Diagram	Remarks
a-Dry steam Power Cycle Type			Opene Cyle
b- Single flash Power Cycle Type			Opene Cyle
c- Double flash Power Cycle Type			Opene Cyle
d- Binary Power Cycle Type			Closed Cyle

W_h: Wellhead C: Kondenser G: Generator

S : Seperator P: Pump

R : Reinjection H: Heat exchanger

T : Turbine W_b: Wellbottom

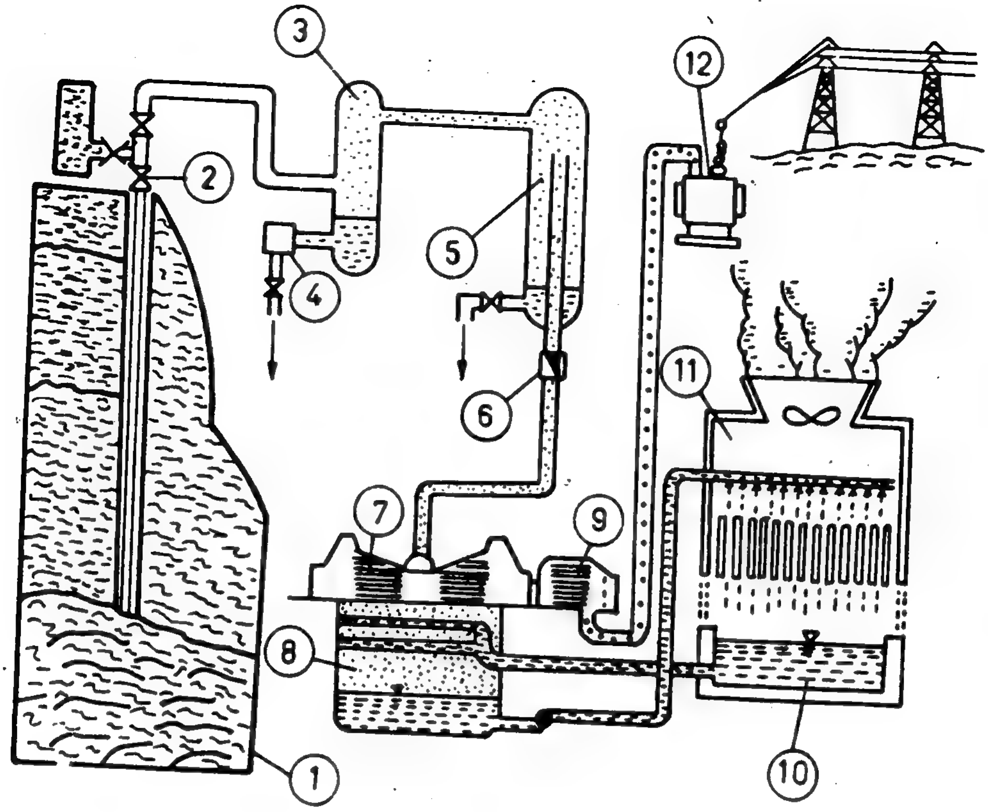


Figure 2.Outlined System of Kizildere Geothermal Power Plant

1. Geothermal resource
2. Operation valve
3. Separator
4. Water collecting tank
5. Main Separator
6. Check Valve
7. Türbine
8. Condenser
9. Generator
10. Cooling Water Tank
11. Cooling Tower
12. Transformator

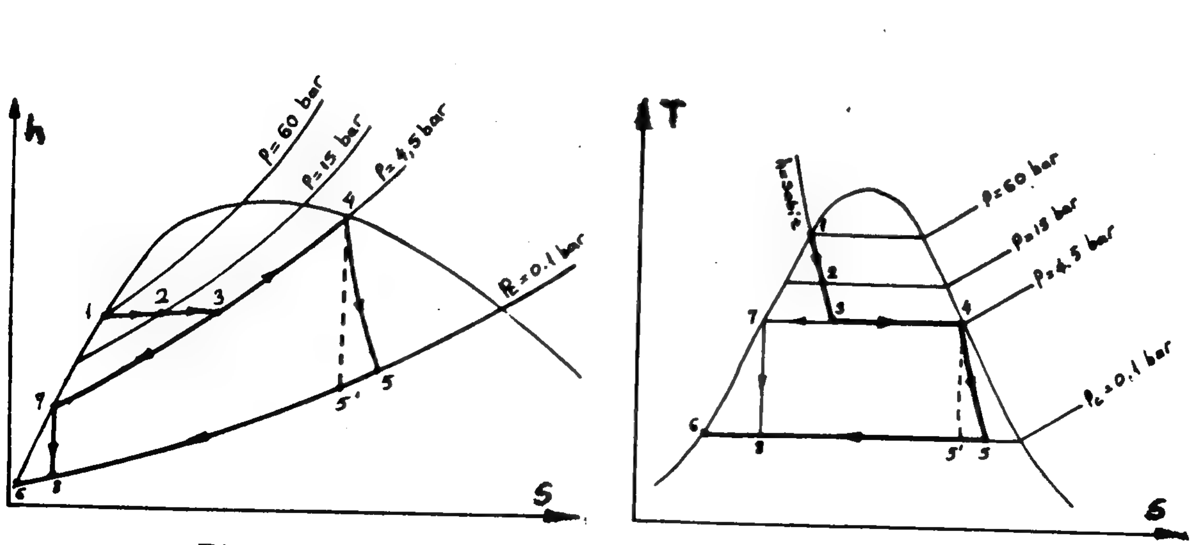


Figure 3. Thermodynamic cycle of The Power Plant

"THE OXYGENATES"

LITERATURE SURVEY AND PROSPECTIVE USE IN LIBYA

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1. ABSTRACT

Gasoline specifications have witnessed many changes over the last twenty years owing to the development of the auto engines, and refiners have found themselves obliged to cope with such developments and to meet the challenge.

Due to more advanced and stringent air pollution standards, the lead compounds addition to the gasoline had to be decreased, or in some countries, to be completely banned. This by far created the biggest challenge to the refiners as far as gasoline specification requirements were concerned. In addition to the lead reduction, the emmission of other pollutants like carbon monoxide, nitrogen dioxides, and hydrocarbons, were also limited in the auto exhaust. The banning of the use of lead compounds, or even their reduction, created what is known in the petroleum industries by the "Octane Gap".

In order to alleviate the impact of the Octane Gap, the refining industries soon started the search for lead compound alternatives. Obviously the ready tool available,was the conventional refining processes. In addition to this route, many refiners found the use of low chain alcohol and ethers, or "The Oxygenates", to be competitive in some instances as an octane boosting tool, and in some others as a gasoline extender.

The potential use of the Oxygenates however, have varied in the past from one country to the other, and in any one country it was varied from one refinery to the other, based on location, legislative actions, crude oil prices and energy needs of each country.

2. LITERATURE SURVEY OF THE COMMONLY USED OXYGENATES

2.1 Methanol

* Currently employed with Azzawiya Oil Refining Company, Technical Service Department, P.O. Box 6451, Tripoli, Libya.

The blending research octane number as well as the blending motor octane number as shown in Table (1), Appendix A, in addition to the low cost of Methanol and its availability, makes this a very desirable component for gasoline blending, but other properties of Methanol, i.e. its high blending vapour pressure, water solubility, elastomer attack tendencies, and low calorific value will more than offset the previously mentioned advantages of Methanol blending. In order to utilize the Methanol blendings within the restrictions given by its undesired effects, it was used in conjunction with higher chain alcohol such as the gasoline grade tertiary butyl alcohol (GTBA).

The European Community Council Directive 85/1536, allows only a maximum of 3% Methanol admixture with 2% cosolvent alcohol, see Table (2) in Appendix A, [4]. Higher additions of Methanol to the gasoline can only be accomplished through modifications of auto engines and segregation of the fuel distribution networks. In line with this Direction, West Germany has under research at present, the M15 (15% Methanol and 85% Gasoline) as well as the M100 (100% neat Methanol), [2].

The potential use of Methanol in gasoline blending is foreseen through the indirect route of MTBE addition. However the biggest potential use of Methanol is only foreseen in its neat form, since it suits very well into the position of the alternative fuel due to its versatile production means through natural gas, coal gasification, and various refuse. This potential however will depend, to a large extent, on the automobile engine manufacturers for the commercialisation of the neat Methanol engines, and it will equally depend on the future crude oil prices.

2.2 Ethanol

This alcohol is manufactured by the fermentation of the agricultural products, and it was used on a large scale in South America in Brazil either as a blend with gasoline or in its neat form. The blending of Ethanol in gasoline was also practiced in several locations in the United States and marketed under the trade name of "Gasohol".

2.3 Tertiary Butyl Alcohol (TBA)

Tertiary Butyl Alcohol (TBA), was extensively used as a cosolvent to Methanol as mentioned when discussing Methanol. The pioneers in TBA/Methanol admixture commercialisation are ARCO Chemical Company and Union Carbide via the marketing of their trade names Oxinol and Ucranol respectively.

TBA is produced almost entirely as a by-product of Propylene Oxide manufacture, and in this respect both ARCO and Union Carbide are manufacturers of Propylene Oxide.

Another route of TBA production is the hydration of Isobutylene. However this route is competing against the use of Isobutylene to produce MTBE. It is not found anywhere in the literature that such a plant is being built, but rather the opposite is being done by ARCO Chemical Company when it converts the TBA in one of its European plants through dehydration to Isobutylenes.

2.4 Isopropanol (IPA)

Isopropanol physical and blending properties with regard to its blend-

ing research and motor octane numbers and the blending RVP, will rate this alcohol superior to Methanol, Ethanol and Tertiary Butyl Alcohol. IPA is produced by the hydration of Propylene.

2.5 Methyl Tertiary Butyl Ether (MTBE)

MTBE was introduced in 1973 as an octane enhancer to be used for the production of the low lead and the unleaded gasoline grades. It is very important to recognise that most of the alcohols discussed earlier are viewed by many as gasoline extenders. Only MTBE, and due to its octane boosting effect, is regarded as an octane enhancer and at the same time as a gasoline extender.

In addition to its excellent octane ratings, MTBE exhibits low blending RVP and low water solubilities, and these have further encouraged its use with no fear of all the drawbacks of alcohol blendings. The MTBE/gasoline blends can be handled, shipped and distributed via the normal gasoline channels. The MTBE allowed concentration in gasoline can be as high as 10-15% governed by the total oxygen limits set by legislation.

The production route of MTBE is by reacting Isobutylene produced from steam crackers or fluid catalytic crackers with Methanol. The other route of MTBE production will be by making Isobutylene available through the Isomerization and dehydrogenation of field butane, Figure (1), Appendix B. Irrespective of the high investment required for this type of plant, decisions to build them were taken by some countries, especially those in possession of field butanes. One plant of this type is expected to be put on stream this year in Saudi Arabia with an annual capacity of 500,000 tonnes, sponsored by IBN-ZAHR Company, a joint venture between SABIC, APICORP, NESTE OY and ECOFUEL [3]. Another plant with the same capacity is under construction in Jose, Venezuela.

3. THE ECONOMICAL IMPACT OF OXYGENATES BLENDING

In discussing the economical impact of Oxygenates blending, it is very important to have in mind that, in the absence of legislative programmes calling for lead reduction, the Oxygenates blending is not economically viable. The addition of lead compounds for the increase of the octane number is always proved to be more economical than the use of the Oxygenates or even by means of the refining processes as shown in Appendix B, Figure (2), [5].

The octane improvement cost by the Oxygenates is reported to be, in the favourable cases, comparable to the cash costs (excluding the investment element) of raising the octane via the conventional refining processes, [5]. The octane enhancement through the use of lead compounds is reported to be cheaper by 5-10 times than the costs of raising the octane through the Oxygenates or refining processes [5].

Chem System International Limited have carried out a study for the evaluation of the different oxygenates in gasoline blending [5]. The result of this study was the determination of a break-even value (BEV) for each oxygenate expressed as a percentage of BEV of the gasoline beyond which oxygenates blending will not be economically justified. In order to arrive to the break-even value (BEV) of each oxygenate, the positive value of this oxygenate (octane enhancement) is adjusted by considering the other negative values (namely volume change and butane back-out) as shown

in Appendix B, Figure (3), [5].

In conclusion, the decision by a refiner to use the oxygenates will depend on the final economical evaluation of all the alternatives available to him. The final evaluation will be affected to a large extent by his break-even value of the gasoline, the value of the available oxygenates and the prevailing gasoline prices. Figures (4) and (5) illustrate the BEV for MTBE and Oxinol and the actual market prices for the gasoline and for the oxygenates. However, other factors rather than economics could dictate the use of oxygenates, like legislative actions requiring lead reduction or a minimum oxygen content in gasoline for the reduction of carbon monoxide emissions, as is the case in the State of Colorado in the United States.

In Azzawiya Refinery a study was carried out to determine the economical viability for the use of the commercially available oxygenates, namely Oxinol 50, Oxinol 60 and MTBE. The results of such a study are tabulated in Table (3), Appendix B.

Out of the oxygenates considered, MTBE was the most expensive oxygenate, mainly due to its high cost compared to current gasoline prices. Therefore, MTBE addition, taking into consideration the production of the existing gasoline grade with the prevalent lead content, will not be economically viable. The Oxinol blending without considering the impact of butane back-out effect, however, shows a good margin of profitability. It is also clear that the lower the octane ratings of the gasoline and hence the larger the quantity of gasoline production the more the eonomical impact of the Oxinol blending.

The study carried out in Azzawiya Refinery showed that the low lead gasoline production in Azzawiya Refinery without the MTBE/Oxinol addition will increase considerably the platformer severity, and in the case of the non leaded, the Refinery will not be able to make unleaded gasoline even with MTBE addition without backing out some quantity of light naphtha.

4. THE ENVIRONMENTAL IMPACTS OF OXYGENATES BLENDING

In the Abstract of this Paper, it was pointed out that the use of oxygenates had started in response to the lead phasedown. With this respect it is obvious that oxygenates contributed to the making of low lead or unleaded gasoline. This contribution can be considered a positive impact when considering the effects of oxygenates on the environment.

It has been reported also that oxygenates, due to their excellent burning properties, will contribute to better combustion with consequent reductions in carbon monoxide emissions up to 19% with a blend of 5% Ethanol and 2% TBA, [6]. Counting on this phenomena alone, the State of Colorado in the United States has already mandated a legislative action requiring a minimum of 1.5 wt.% oxygen in gasoline as a first step, to be increased to 2 wt.% in the following year for the winter period.

Other emissions such as hydrocarbons and nitrogen oxides will not see any improvements as a result of oxygenates blending, and in some studies these values were reported to be marginally higher, [7].

In connection with oxygenates impact on environment, it was also reported that aldehydes, formic acids and acetic acids will increase in the

case of oxygenates blends compared to premium gasoline, [7]. As far as ozone concentration is concerned, the oxygenates blends, owing to their negative effect on hydrocarbon and nitrogen oxides emissions, are expected to contribute to the worsening of the ozone ground level problem. However, the oxygenates, and in their neat form, will contribute dramatically to the reduction of the ozone and consequently the photochemical smog.

In a rather indirect way, oxygenates blending, especially MTBE in gasoline, will decrease the use of benzenes and the carcinogenic poly-nuclear aromatics significantly and contribute positively to cleaner and safer environment.

5. POTENTIAL OF OXYGENATES PRODUCTION AND USE IN LIBYA

Out of the previously mentioned oxygenates, only Methanol is in current production in Libya with a capacity of 2,000 tonnes per day. In addition, only one MTBE plant with a capacity of 47,000 tonnes per year is in the planning phase in Ras Lanuf. This MTBE plant will require approximately 17,000 tonnes per year of Methanol.

A further oxygenates production route will be through the hydration of the excess propylene, which is approximated to be 100,000 tonnes per year, to Isopropanol. This route will produce about 139,000 tonnes per year of IPA. However, taking into consideration the maximum limit of 3% volume Methanol, and the current local consumption of gasoline in Libya, only 44,400 tonnes of 60 : 40 admixture of Methanol and Isopropanol can be used, and the rest of the Isopropanol (116,800 tonnes per year) will have to be sold outside Libya, either as neat IPA or mixed with Methanol. It is very important to note that the potential use of Methanol as a fuel component will be through the indirect way in MTBE manufacturing, since it is calculated that Methanol this way can be added in as high as 4.8% vol. to the gasoline compared to only 3% vol. of Methanol in the cosolvent admixture.

Taking into consideration the planned MTBE plant capacity in Ras Lanuf, and even if the propylene hydration plant is built, the total Methanol use will not exceed 39,200 tonnes per year, equivalent only to 20 days production of Methanol plants.

Since MTBE allowable addition is as high as 10-12%, and the planned capacity in Ras Lanuf will be used locally to make possible the production of the unleaded gasoline, it is recommended to study the possibility of building a large scale MTBE plant based on field butanes with a capacity approaching the previously mentioned units of 500,000 tonnes per year. This unit will augment MTBE supply of the small units like the one in Ras Lanuf or any other small plant to be built in future, in case of maintenance or emergency shutdowns. Such plant will also enable the national refineries to produce the low lead and the unleaded gasoline. In the absence of such a plant and in view of any lead reduction policies, the local refineries will find it obligatory to import MTBE.

The economics of these large scale plants will depend on MTBE selling price, gasoline selling price and the prices and the availability of raw materials (butanes and Methanol).

6. CONCLUSION

Oxygenates blending in the gasoline pool is experienced by many

refineries in order to overcome the "Octane Gap" created by the lead phase down.

Methyl Tertiary Butyl Ether (MTBE), Ethanol and Methanol (in conjunction with cosolvents, i.e. TBA and IPA) are considered the most widely accepted and used oxygenates.

The oxygenates use will not be by any means a substitute for the lead compounds, since the latter is considered an additive and only small amounts can boost the octane significantly, while the oxygenates are considered a blending component where a good blending quantity is required to get only one or two octane numbers increase in the gasoline pool. This will suggest that refineries planning to produce low lead or unleaded gasoline will find it obligatory to increase the gasoline pool via conventional refinery units in addition to the use of the oxygenates.

It was foreseen that the deciding factor for the oxygenates use will be the economic cost benefit analysis for each particular refinery. In addition, it is also expected that the legislative actions concerned with the environmental pollution as regards lead reductions and/or the requirement of a minimum oxygen content, will also be a deciding factor for the future use of the oxygenates. Within the oxygenates themselves and in view of future volatility restrictions of the gasoline, MTBE is expected to take the lead due to its low RVP.

In Libya, the oxygenates are not currently used. However, their use is expected in the near future barring any gasoline lead reduction policies. In order to enable our local refineries to produce the low lead or the non leaded gasoline, it is recommended to consider the modification of one of the Methanol plants to have the flexibility for the production of a mixture of Methanol and higher chain alcohol to be used in gasoline blending. A large MTBE plant based on field butanes is also recommended to be considered to augment the production of the small MTBE plants which could be built in future, and the excess from this unit is expected to find good marketing opportunities in the European market.

In case such a plant will not be built and national refineries will be required to produce unleaded gasoline, then the MTBE requirements will have to be met through MTBE imports.

A further production possibility does exist for Isopropanol (IPA) in Ras Lanuf Refinery and Petrochemical Complex through the hydration of the excess propylene which is estimated to reach 100,000 tonnes per year.

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APPENDIX A

TABLE (1)

TYPICAL BLENDING PROPERTIES OF OXYGENATES

		BLENDING RON CLEAR	BLENDING MON CLEAR	BLENDING RVP (psi)	BLENDING SPECIFIC GRAVITY
Methanol	5%	128	97	60	0.790
Ethanol	5%	126	97	25	0.785
IPA	7%	114	98	15	0.770
TBA	7%	105	95	10	0.765
MeoH/TBA (3:3)	6%	117	96	29	0.770
MeoH/TBA (3:2)	5%	119	96	34	0.770
MTBE	10%	118	101	8	0.740

Basic Data European Fuel Oxygenate Association SOURCE Ref: (1)

APPENDIX A

TABLE (2)

EEC DIRECTIVE 85/1536

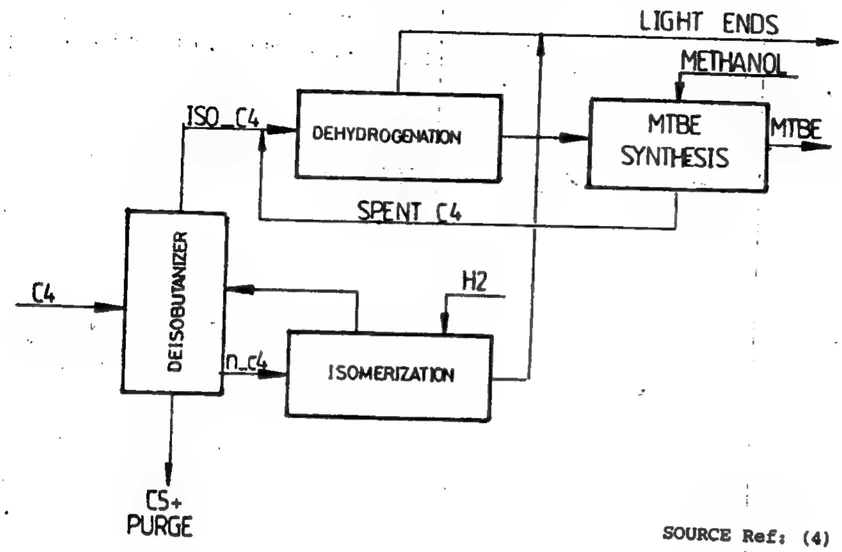
SUBSTITUTE FUELS	A	B
Methanol, suitable stabilizing agents must be added *	3% vol.	3% vol.
Ethanol, stabilizing agents may be necessary *	5% vol.	5% vol.
Iso-propyl alcohol	5% vol.	10% vol.
T B A	7% vol.	7% vol.
Iso-butyl alcohol	7% vol.	10% vol.
Ethers containing five or more carbon atoms per molecule *	10% vol.	15% vol.
Other organic oxygenates defined in section 1	7% vol.	10% vol.
Mixture of any organic oxygenates** defined in section 1	2.5	3.7
* In accordance with national specifications or, where these do not exist, industrial specifications ** Acetone is authorized up to 0.8% by volume when it is present as a by-product of certain organic oxygenate compounds.	Oxygen weight, not exceeding the individual limits fixed above for each component	

SOURCE Ref. (5)

APPENDIX B

FIG (1)

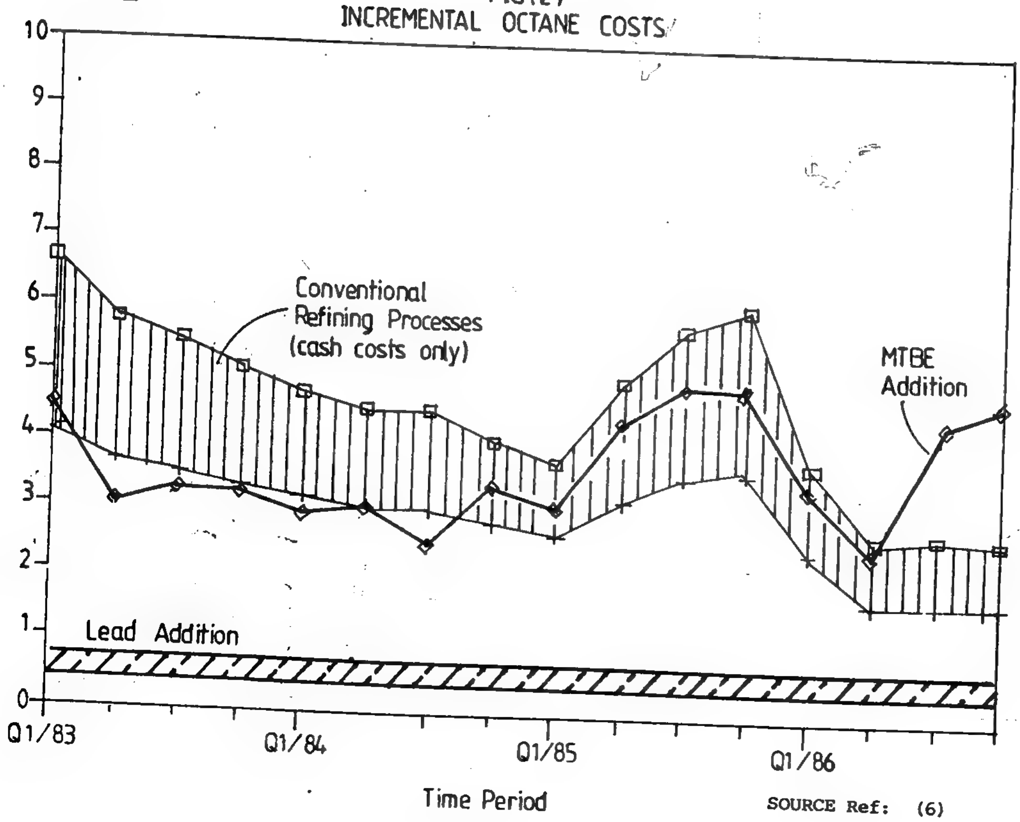
MTBE PRODUCTION FROM FIELD BUTANES



SOURCE Ref: (4)

APPENDIX B

FIG(2)
INCREMENTAL OCTANE COSTS

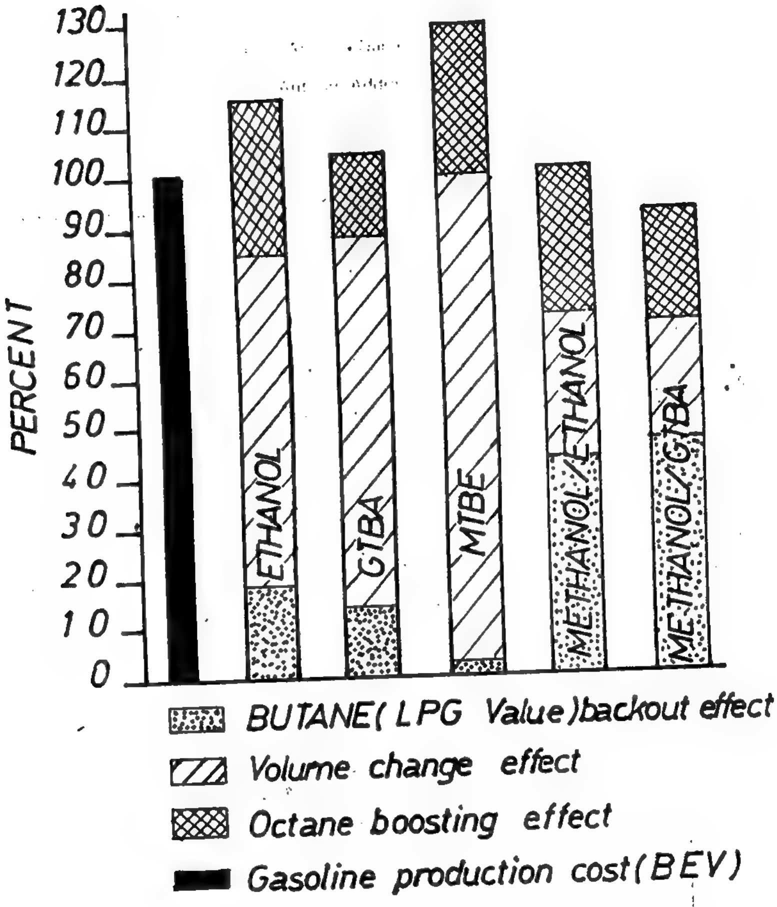


SOURCE Ref: (6)

APPENDIX B

FIG_ 3

OXYGENATES BREAK EVEN VALUE COMPARISON
(as percent of gasoline BEV)



SOURCE Ref: (6)

APPENDIX B

TABLE (3)

ECONOMICAL EVALUATION OF OXYGENATES USED IN AZZAWIYA REFINERY

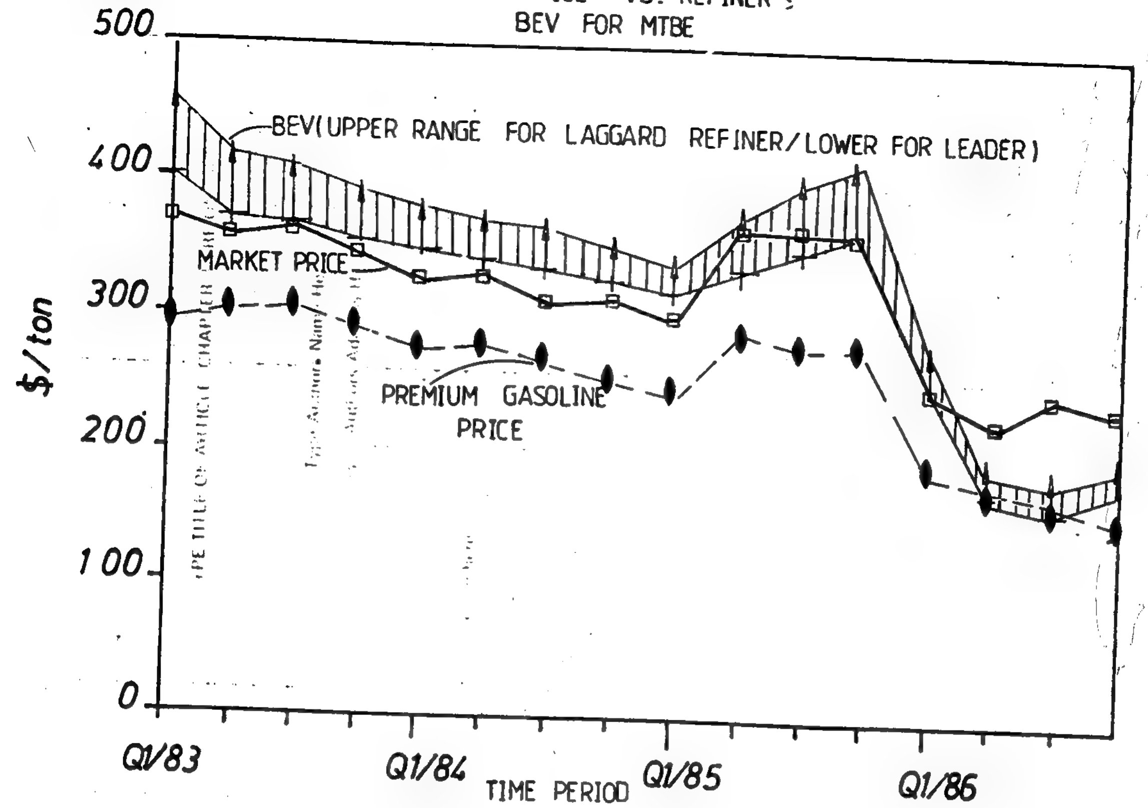
TYPE OF GASOLINE TO BE PRODUCED	OXYGENATE TYPE	ECONOMICAL IMPACT
98 RON with 0.8 gm/lt. lead content max.	OXINOL (9% vol. addition)	Positive Category (A)
	MTBE (11% vol. addition)	Negative Category (C)
94 RON with 0.4 gm/lt. lead content max.	OXINOL (9% vol. addition)	Positive Category (C)
	MTBE (11% vol. addition)	Negative Category (A)
98 RON with 0.4 gm/lt. lead content max.	OXINOL (9% vol. addition)	Positive Category (B)
	MTBE (11% vol. addition)	Negative Category (B)

Positive Category (A) = The most economical case

Negative Category (A) = The least economical case

APPENDIX B

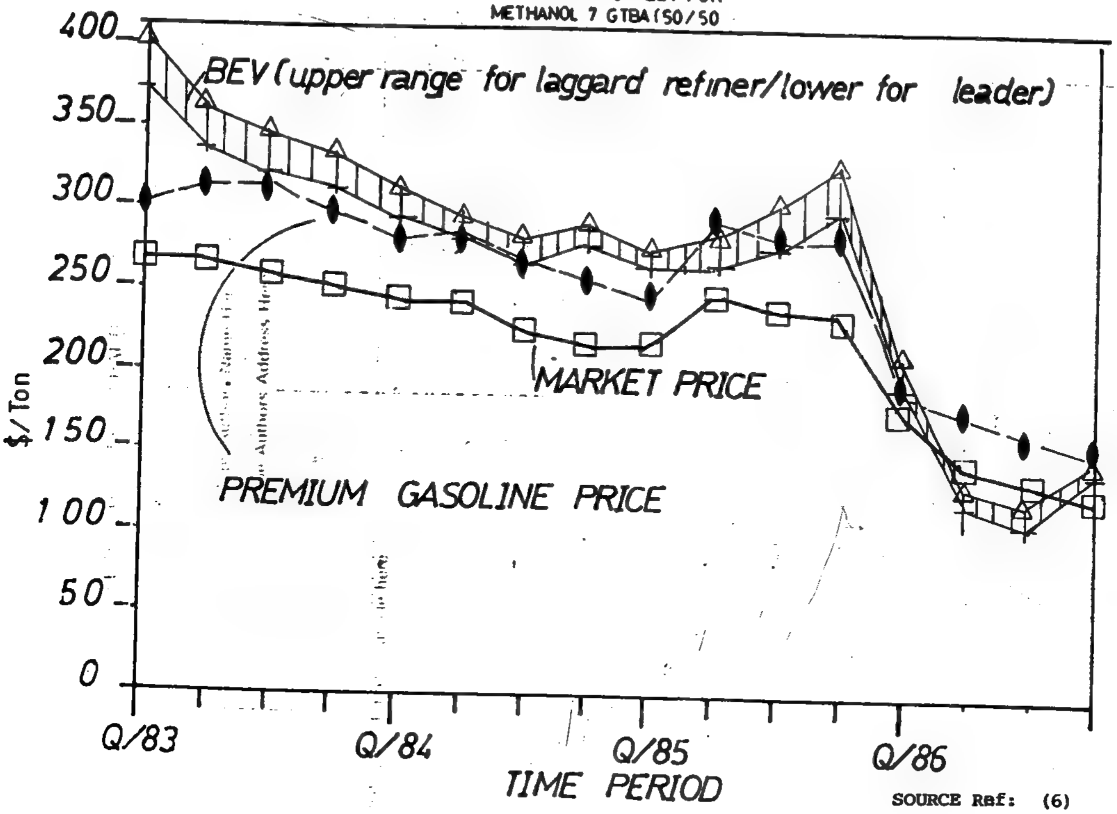
FIG(4)
MARKET PRICE VS. REFINER'S
BEV FOR MTBE



SOURCE Ref: (6)

APPENDIX B

FIG(5)
MARKET PRICE VS REFINER'S BEV FOR
METHANOL 7 GTBA (50/50



SOURCE Ref: (6)

METHANOL FUELLING OF 2- STROKE, 50 CC ENGINE

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and

Sanjeev Ahuja,
Rupendra Kaushik

ABSTRACT

The field and laboratory tests performed at Jaipur,India have demonstrated that a moped can be run on 100% methanol with minor alterations in the existing petrol engine. This is a break-through in the use of Methanol. Earlier,only a percentage of Methanol mixed with gasoline was experimented with on small two-stroke moped engines. The implications of using 100% Methanol are wide and for reaching. While Petrol is sarce and expensive, methanol can be mass produced cheaply from easily available and renewable raw materials. Our studies have demonstrated that a moped can be run without petrol. The engine performance with methanol was found to be superior to that with Petrol. Detailed field rests were conducted under various city and highway conditions. Startability was uniformly good. Performance with pillon rider,at cruising,was better than that with petrol,and acceleration was excellent. Fuel economy was comparable with gasoline. Emission levels with methanol were found to be more acceptable environmentally.Problems of material compatibility have also been successfully over came.

1. INTRODUCTION

With depletion of valuable petroleum resources,it has become imperative to evaluate the performance of I.C.Engines on fuels other than gasoline. Our petroleum resources will be exhausted within next few decades, if the rate of consumption does not decline. It is therefore important to search for such alternate fuels which can run the existing engines with slight modifications.

A number of studies [1] conducted in this field in various countries have proved that methanol can be used as a potential alternate fuel for existing spark ignited engines with little modifications. Its lean burning limits, high octane number and

low pollution level make it an ideal substitute for gasoline.

Studies on four stroke engines[2] using methanol as a sole fuel and in blends are many but as far as two stroke engines are concerned, very little work has been done using neat methanol(100%).

In India, two-stroke-engine-powered vehicles constitute half the total population of all types of vehicles. Out of these, two-stroke, 50 c.c. moped engines form an important category. Use of Moped (a kind of mobile powered by small 2-stroke S.I. Engine)is multiplying at a rapid rate due to its high average(upto 90 km/lit)and low maintenance. India alone has an annual turnover of about 25,0000mopeds and the world wide production figure would touch a million mark. It was therefore decided to take up a research project using pure methanol as the fuel for two stroke 50 c.c. moped engine.

Extensive field trials were carried out using neat methanol(100%) as a fuel, Minor changes in the carburetter became necessary since the properties of methanol are different from those of gasoline. The results are presented here.

2. TEST PROGRAMME AND PARAMETERS STUDIED:

The moped was evaluated for its performance in hot and rainy seasons, in temperature range 23-40^{0}C (hot and humid conditions). Different parameters like Driveability, Engine condition, Deposits, Exhaust emission, Temperature of different engine parts, Fuel economy, Material competability etc.were studied.

Field trials under various city and highly conditions were conducted. A standard route of 80 Kms.which included a variety of city and highway conditions was selected and the moped was run on this route for a total of 700 Km (excluding 500 Km. of run- in period)on neat Methanol. Similar test was carried out using gasoline.

Break up of the route:

S.No.	Condition	Kilometers
1.	City (crowded)	18
2.	Smooth Road (highway)	50
3.	Hilly Area	8
4.	Uneven surface	4
	Total :	80 Km

During standard run, different driveability parameters like starting, warm up, idling, cruising, acceleration etc.

were studied and temperatures of different engine parts were measured after each 5 Kms. which were compared with the results obtained with gasoline. Each time,fuel economy was evaluated per litre of fuel.

2.1 Vehicle : A popular make of moped (50cc engine)was selected for this study. The specification of the vehicle are given in the Appendix(I).

For 100% methanol, alterations in the existing Carburetter were necessary(Seel Appendix II). As the calorific value of methanol is lower than C.V. for petrol, the jet size was increased accordingly.

2.2 Test Fuel: 100% methanol was used as a fuel. Since 2T-oil (the conventional 2-stroke,lubricant) is not miscible with methanol, castor oil' was tried and found miscible and suitable as a lubricant. During run in period 6% castor oil and later on 4½% castor oil was used for lubrication,which gave satisfactory results. To prevent phase separation between methanol and castor oil at low temperature, 1.5% Iso-butyl Alchol was added as solubilizer.

No petrol was required for cold starting. Mopeds were generally run in conditions above 8°C at which temperature methanol evaporates easily. With gasoline however, 4%,2T-oil was used as lubricant as usual.

3. RESULTS AND DISCUSSION:

3.1 Driveability: On a standard route of 80 Kms. driveability tests were performed. As shown in the Fig(1)these tests proved that starting with methanol as a fuel is better than with gasoline, though starting with gasoline was also good. Acceleration and cruising were excellent with methanol and even better than with gasoline. However, 'idling' was not as good as it should have been . Other then during idling driveability demerits were lower as compared to gasoline,which reflects a superior performance with methanol fuel. Performance with a pillion rider was found to be better as compared to gasoline.

3.2 Fuel Economy : The plot of fuel consumption is shown in Fig.(2) for both gasoline and methanol under moderate and rainy conditions. It is seen that although the fuel consumption during rainy condition was higher for both the fuels, fuel consumption in case of methanol in both conditions, was slightly more than that with gasoline.

3.3 Maximum Speed: As shown in Fig.(3) the maximum speeds obtained with methanol in different road conditions were found to be greater compared to gasoline. This suggests that power out put with methanol is greater as compared to that with gasoline.

3.4 Temperature of various engine parts: On the standard route of 80 Kms, temperature of various engine parts like spart plug tip,cooling fins etc.were taken at the interval

of every 5 Kms. The plot between temperature and distance is shown in Figs. (4) & (5). The curves of temperature with gasoline are always above the curves for methanol. From these plots it can be derived that temperatures of various engine parts are always lower with methanol and hence engine runs cooler as compared to that with gasoline. The reason could lie in the high latent heat of vaporisation of methanol.

3.5 Temperature of exhaust gases: Temperature of exhaust gases were also measured at every 5 Kms. With methanol, the temperature of exhaust gases were found to be lower than with gasoline as shown in Fig.(6). It can be seen in the figure that curve for methanol is always below that for gasoline. Lower exhaust gas temperatures indicate a higher thermal efficiency.

3.6 Exhaust emission characteristics: Using HORIBA-MEXA 201 E GAS ANALYSER, it was found that CO emissions are less with methanol at idling and at wide-open throttle(WOT) Conditions than with gasoline. This is shown in Fig.(7) NO_x emissions are likely to be lower with methanol than with petrol as the temperature of combustion chamber is lower. [3,4].

3.7 Deposit and Wear : After completion of 1200 Kms.(including 500 Kms. of "Run-in"Period), the engine was dismantled and photographs of piston,cylinder head etc. were taken.The castor oil worked as a satisfactory lubricant. Visual inspection of cylinder head,spark,plug,piston etc.revealed no ring groove deposits. Photographs also proved that the Piston rings were free and there were no scuffing marks over the piston and inside the cylinder.The blockage of exhaust port was minor and acceptable.The crank case deposits were found to be within acceptable limits.

3.8 Material compatibility of Carburatter Parts: The plastic float of carburetter swelled initially and caused overflow problem. It was covered with silver foil and it worked temporarily. But a lasting solution was to use a copper float. However,the colour of brass parts changed and minor corrosion was noticed. The use of nickel and chromium plated parts may solve this problem. The fuel was stored in conventional steel tank which has shown no problems.The plastic tube which connects fuel tank to carburettor became hard. The viton tip of float needle has caused no problem. The gaskets and sealings are also working satisfactorily. But it would be better if these are made of methanol-resistant material like poly-acetyl 3 . The brass jet became blackish red.

4, MODIFICATION

Minor alterations were carried out in the carburettor e.g. main jet size was increased to allow more fuel to flow, as fuel air ratio with methanol is greater compared to gasoline. Jet,size 80(0.8 mm dia.)worked satisfactorily. However,it needs optimisation.

Following are the modifications:

S.No.	Part	Original	Modified
1.	Main Jet	52.5	80
2.	Float	Plastic(viton)	Covered with silver foil

5 SUMMARY

From the results obtained so far, following conclusions can be drawn:

1. Better driveability in normal climatic condition than gasoline.

2. Increased maximum speed and hence more power from the same engine compared to gasoline.

3. Slighly lower fuel economy which can be overcome by optimizing spark timing, main jet size . However it will be more economical to run the engine on methanol due to lower production cost compared to the price of gasoline.

4. Wear and deposits are with-in acceptable limits.

5. Idling is poor with methanol as compared to gasoline.

6. Engine runs cooler with methanol as compared to gasoline.

7. Exhaust emissions are comparable to that with gasoline.

From the above, it can be said that with minor alterations which are easily possible a moped can be conveniently switched over to methanol fuel. Aslo, as methanol can be produced cheaply, unlike gasoline, it will help in reducing the dependance on gasoline for two wheelers.

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APPENDIX -I

SPECIFICATION OF TEST VEHICLE ENGINE(ORIGINAL)

1.	Type	Two stroke,single cylinder air cooled.
2.	Bore	40mm
3.	Stroke	39mm
4.	Displacement	49 c.c.
5.	Compression Ratio	7.4:1

APPENDIX-II

SPECIFICATION OF CARBURETTOR

		ORIGINAL	MODIFIED
1.	Make	IBEX	IBEX
2.	Type	Horizontal, side draft; spigot Fitment	-
3.	Venturi	10mm	10mm
4.	Main Jet size	52.5	80
5.	Float	Viton	(i)covered with metallic foil& (ii) Copper float.

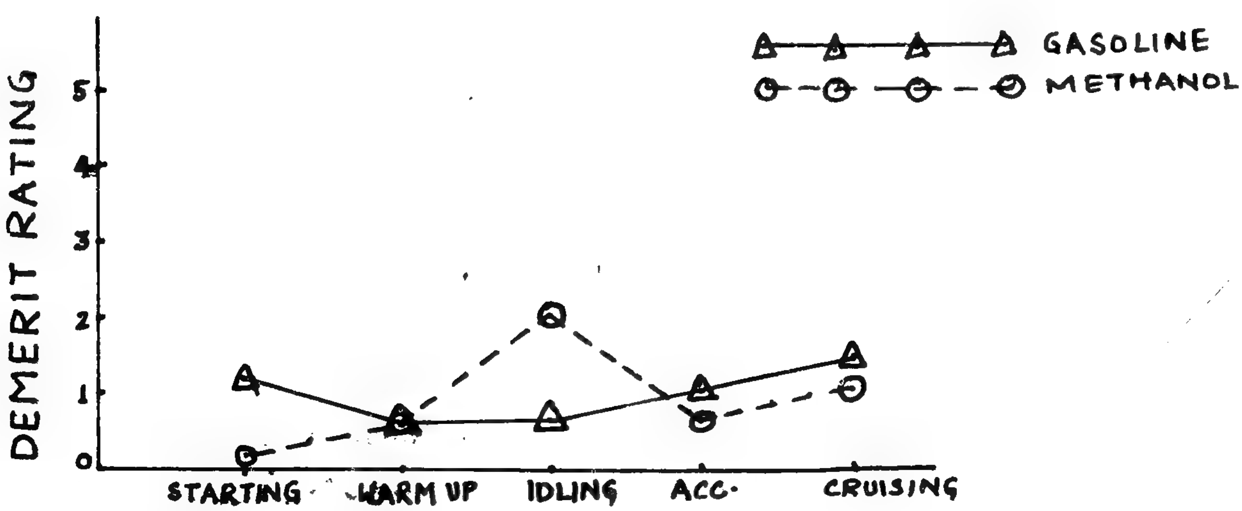

FIG:1 :-DRIVABILITY DEMERITS

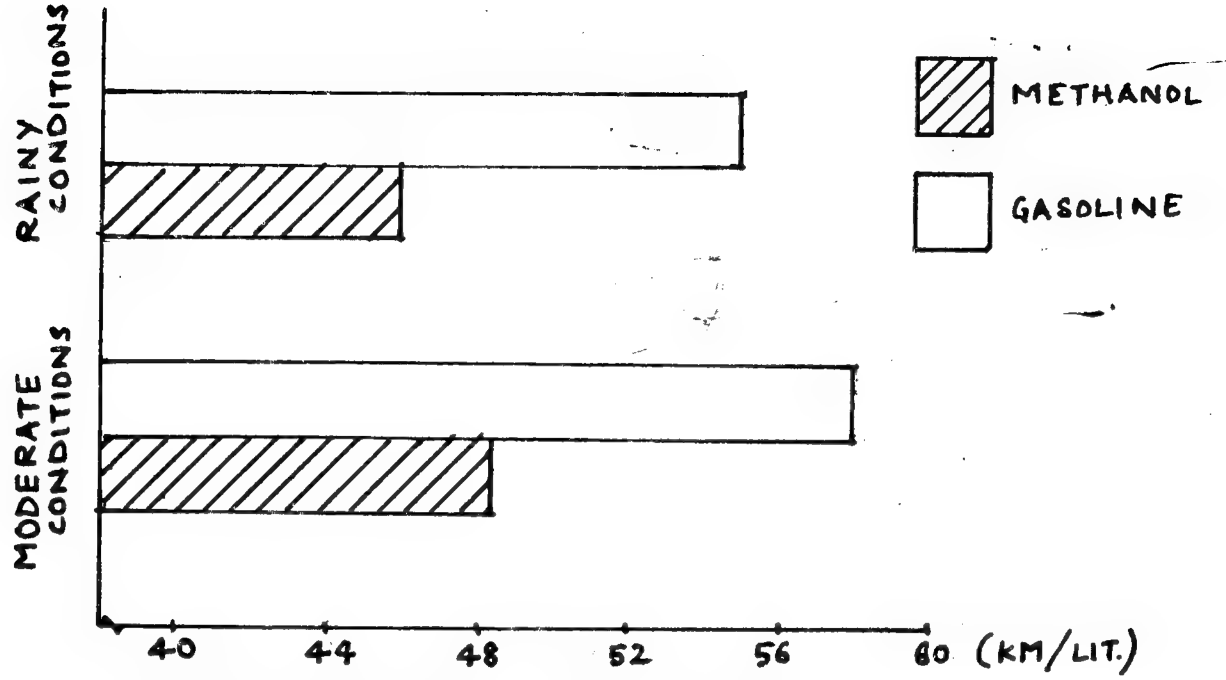

FIG:2 :- FUEL ECONOMY

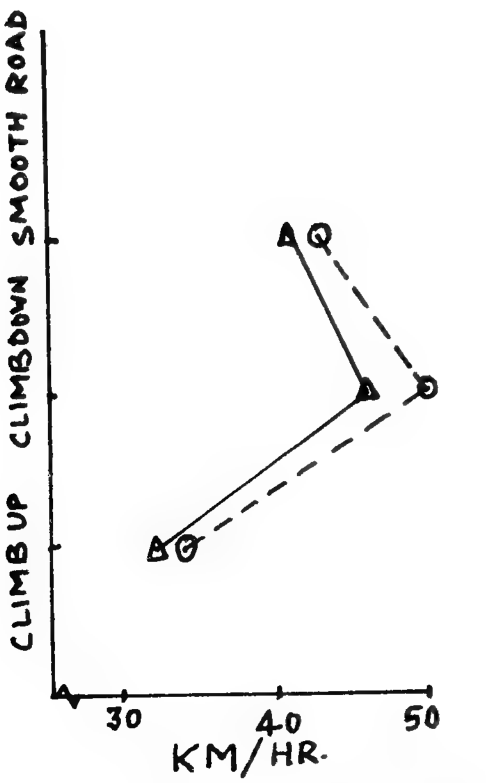

FIG:3:- MAX. SPEED

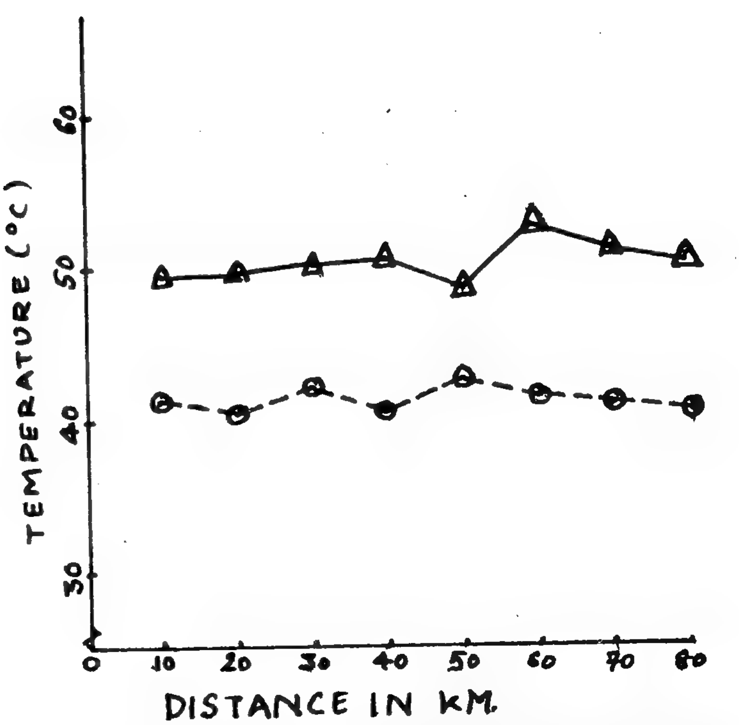

FIG:4:- TEMP. OF SPARK PLUG

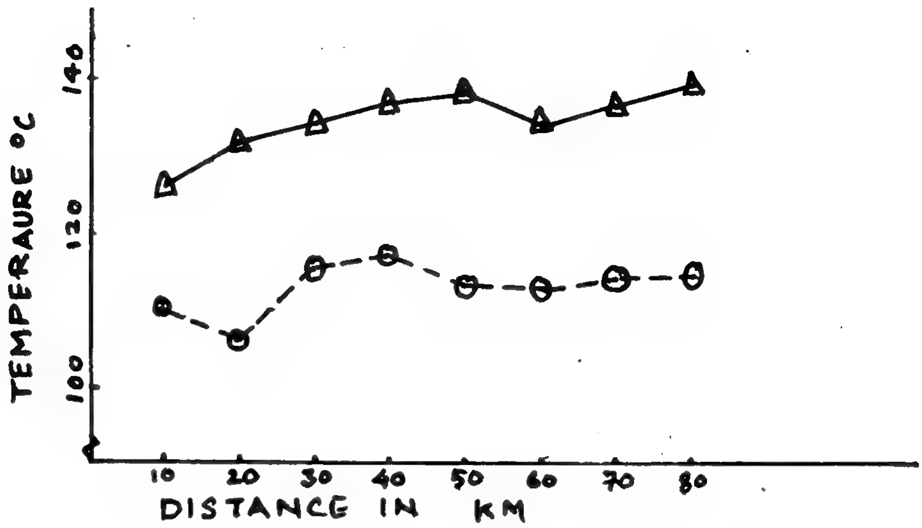

FIG: 5 :- TEMP. OF COOLING FINS

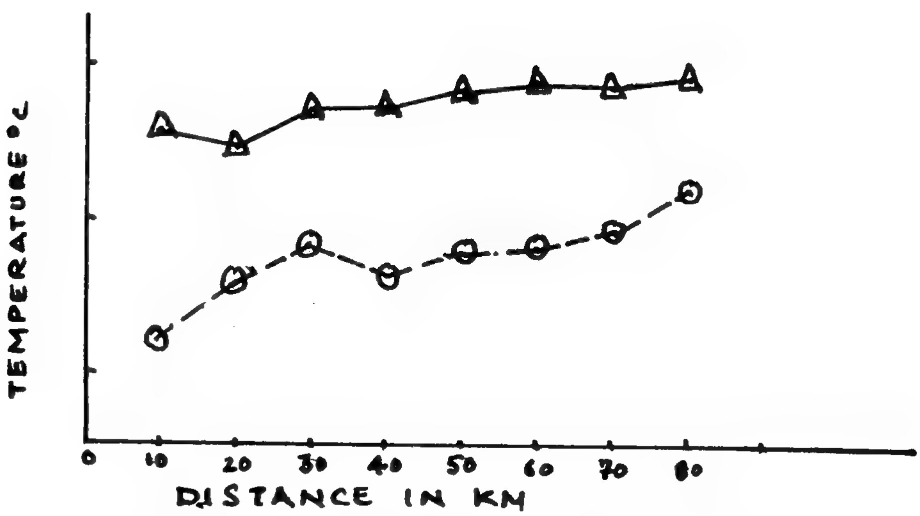

FIG: 6 :- TEMP. OF EXHAUST GASES

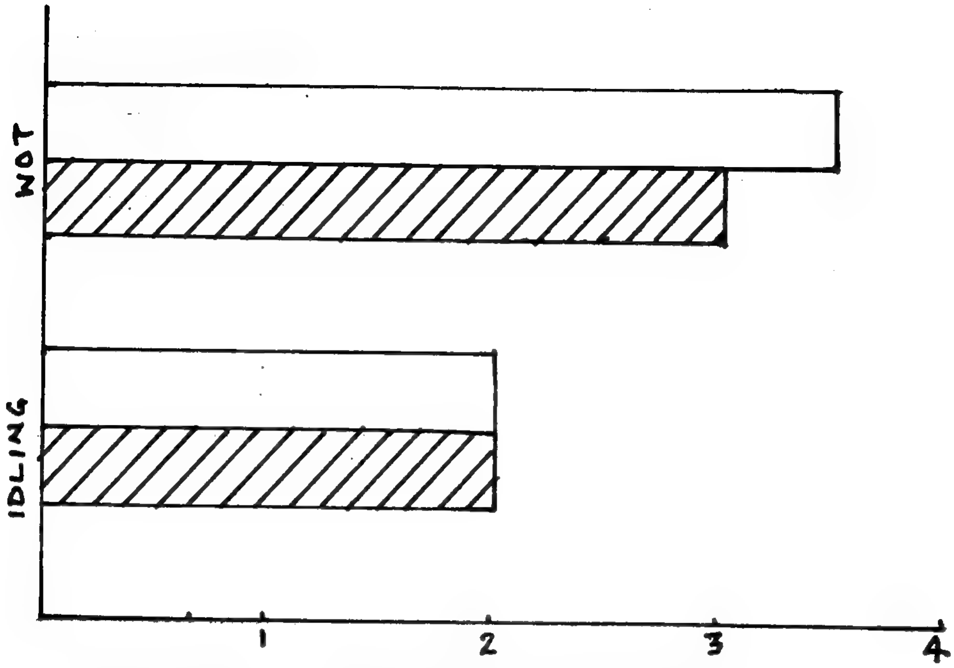

FIG: 7:- CO-EMISSION (%)

THE POTENTIAL OF BIOGAS AS AN ALTERNATIVE ENERGY SOURCE FOR RURAL AREAS OF SUDAN

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ABSTRACT

The energy consumption pattern in Sudan is characterized by an extensive use of wood. This is utilised in the form of firewood or charcoal mainly for household cooking. The rapid depletion of forests and bush vegetation is a primary cause of deforestation, desert encroachment and drought. To help ease this potentially dangerous situation, wood consumption in rural areas could be replaced by biogas utilising renewable, locally available, unwanted animal wastes, crop residues and aquatic weeds. It is shown here that 57.5 million MT of wastes and residues per year could be made available for biogas production, by anaerobic digestion, on family-size units. The amount of gas produced will be equal to 4.2×10^9 m^3 or 8.8×10^{16} J per annum. This amount will totally replace all wood consumed by rural households resulting in a net saving of 67.8 million m^3 of wood growing stock each year. The impact on the country's ecology will be significant. Additional benefits are better health, hygiene and sanitation, a good fertilizer utilising the left-over slurry, and less environmental pollution.

1. INTRODUCTION

Sudan, being a non-oil-producing, developing country, is suffering from acute energy deficiency. Since energy is an essential prerequisite for development, the country's energy crisis is adversely and seriously affecting both traditional and modern development sectors.

Sudan's energy crisis is evident by the long queues on petrol stations and severe shortages in electricity supply, which more often results in long hours, sometimes days, of power interruptions. Scarcity of gas oil is limiting the areas that could be irrigated for agriculture. The industrial sector is seriously suffering from limited availability of fuels and months of electricity cuts resulting in large losses of potential revenue. The transport sector is no

exception and difficulties are often experienced in obtaining fuel. As a result, the cost of transportation has increased markedly and long delays in goods and intercity passenger transport are not uncommon. On the domestic level, butagas for cooking and electricity for lighting and other household uses are in serious short supply. On the traditional sector, wood and charcoal are becoming difficult to obtain and prices have rocketed in the last few years. (There is a ten-fold increase in charcoal prices since 1983.)

In 1980, Sudan consumed energy equal to 7 million tons of oil equivalent (TOE)* (1). 85% of this was in the form of wood, charcoal and other biomass; 14% was petroleum products; and 1% hydropower.

Wood, being the major source of energy, is utilised, mainly in the traditional sector for cooking, brickmaking etc. in the form of firewood or charcoal. The utilisation of wood is characterized by a very low efficiency of conversion (less than 15%) and consequently considerable amounts of energy are lost. Likewise, the traditional method of simple earth-covered kilns for conversion of wood to charcoal is highly inefficient and does not allow for the recovery of liquid and gas by-products. Furthermore, the extensive use of wood has a dramatically deleterious impact on the ecology. The rapid depletion of the scarce forest and bush vegetation resources is one of the primary causes for the serious deforestation, desertification and drought problems now experienced by Sudan.

The social and economic cost of deforestation could not be over estimated, and the urgent need for rescuing the environmental quality of the country could not be overemphasized.

This alarming and inherently dangerous situation has prompted the authorities to consider measures of conservation and rationalization of energy consumption on the one hand; and the development of alternative energy sources on the other. On the conservation side, work is being carried out to develop more efficient stoves and kilns with the objective of reducing the amount of firewood consumption and thus helping alleviate the country's deforestation problem. In addition, use of gasification and pyrolysis technologies is being considered to further reduce firewood consumption and increase the amount of energy produced. Besides, research is now being carried out in wind, solar and biomass energy to assess the feasibility of alternative energy sources. Unfortunately, the list of priorities that has been drawn as a result of the initial stages of this work has overlooked the biogas option (1).

The utilisation of microorganisms to convert organic wastes into methane gas (known as biogas) holds a promising potential for meeting the energy needs of the rural population of Sudan. This paper is a preliminary attempt at

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* TOE : A means of comparing the energy values of different energy sources. 1 TOE = 41.8 x 10^9 Joules.

assessing the potential of biogas technology as an alternative renewable source of energy. Attention is focused only on the rural areas of Sudan which comprise 65% of the country's population who use up about 47.5% of the total primary energy resources for domestic applications (cooking, lighting etc.). Ninety nine percent of the energy consumed by the rural household sector is drawn from biomass sources in the form of fuel wood (92%) and crop residues (7%).

The objective of this study is to estimate how much wood could be saved from cutting if the biogas option is nationally adopted. Technical details of the process are not discussed.

2. BENEFITS OF BIOGAS TECHNOLOGY

Compared with other energy options, biogas has numerous benefits which could be classified as technical, environmental and socio-economic:

2.1 Technical: The major advantage of the biogas technology is its simplicity and suitability for application at the village or the individual household level. All that is required to produce the gas (which contains 60-80% methane and 20-40% CO_2) is a suitable container (where a mixture of organic matter and water are dumped and left alone to digest) and gas storage facilities (where the product gas easily accumulates). The units can be constructed from locally available materials and therefore preclude the need for imported equipment or spare parts. Maintenance requirements are also considerably low. Besides, the ability to apply the technology to the individual household level eliminates the need for elaborate and costly collection and distribution systems.

In addition, this technology provides a perpetually renewable source of energy. The gas produced has a high calorific value (21-26 MJ/m^3) (2,3) and could be utilised with high efficiency for cooking, lighting, refrigeration or water pumping using locally-made stoves and lamps, and with little modification to existing gas refrigerators and pumps. (2)

2.2 Environmental: In addition to providing a clean and healthy source of energy, adopting biogas technology provides a convenient way of getting rid of organic wastes and residues; and therefore reducing environmental pollution. Most of the disease-carrying pathogens and parasites die during the anaerobic digestion process (2,3). Moreover, the residual matter after digestion is odourless and does not attract flies.

On the national level, biogas will replace wood as a source of energy, therefore, helping to a large extent alleviate the deforestation problem. This intangible benefit is the most critical and could be quantified in terms of the cost of reafforestation and the irreparable damage to the ecology that current practices will lead to, if immediate

steps, to reverse this process (such as widespread dissemination of biogas technology), are not taken.

2.3 Socio-economic: One great advantage of anaerobic digestion is that the left-over slurry, after the digestion process, not only preserves the nutrient value of the input feed, but also increases the availability of nitrogen (in ammoniacal form) (2,3,4,5). The effluent can be used as a good organic fertilizer and soil conditioner. This added benefit results in better crops and savings on chemical fertilizer consumption. (One kg of effluent - solid basis - contains about $\frac{1}{3}$ of a kg of fertilizer in NPK value) (6).

Economic feasilibity studies in Sudan have shown that a rate of return of 36% for an investment on a family-size biogas unit could be realized (7). The analyses did not include intangible factors such as improved hygiene, better lighting, clean and fast cooking fuel, better crops and conservation of forests and bush vegetation.

3. RURAL ENERGY CONSUMPTION PATTERN

It is estimated that, in 1990, the rural population of Sudan will be about 65% of a total population of 25 million (1). Projections for the year 1990 show that the country's total primary energy consumption will be about 10 million TOE. Table 1 shows the contribution of the major energy sources to different economical-activity sectors (1). Figures 1 and 2 schemetically illustrate this projected pattern. The largest consumer (as seen in Figure 1) is the household sector (75.7% of the total primary energy resources). This is due to the very low efficiencies of conversion by direct combustion of biomass (some reports put it as 4% for open fires and 10% for traditional charcoal stoves) (8).

The total amount of wood consumed, in the form of firewood and charcoal, in 1980 was 5.4 million TOE; 95% of which was consumed by the household sector (5.1 million TOE) (1). Out of this, rural areas consumed 70% of the total household wood consumption, due to the fact that urban areas use proportionally more charcoal, versus wood, and therefore consume more wood equivalent per person.

In 1990, rural household wood consumption for cooking is estimated as 4.88 million TOE (3.02 as firewood and 1.86 as charcoal) (1). This is equivalent to 67.8 million m^3 of growing wood stock*, which represents 68% of a total annual cut of 99.5 million m^3 of growing stock.

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* 1 MT wood is equivalent to 0.43 TOE. It is also equivalent to 3 m^3 of growing stock.

1 MT charcoal is equivalent to 0.72 TOE. It requires 6 MT of wood to yield 1 MT charcoal.

Assuming an efficiency of conversion of 20% (a high figure), the useful energy utilised is, in effect, equivalent to 0.98 million TOE.

4. CURRENT BIOMASS RESOURCES

An important characteristic of biogas technology, which makes it more attractive, is the wide range of organic materials that could be used as substrates for gas production These materials are generally unwanted wastes or residues. The organic matter that could be used for biogas production include:

- Animal wastes: animal manure, poultry droppings, etc.
- Plant residues: wheat, sorghum and cotton straw, plant leaves and trimmings, ground-nut shells, cotton-seed trash, rice husks, etc.
- Domestic organic wastes: kitchen refuse, etc.
- Sewage wastes.
- Industrial organic wastes: food-processing plants, slaughter houses, etc.
- Aquatic weeds: water hyacinth, papyrus, etc.

Sudan, having an economy dominated by agriculture and animal production, is rich in animal and agricultural wastes. The livestock population is estimated at 52 million heads in 1990, including over 20 million heads of cattle (7). Table 2 shows the number of livestock and the amount of manure produced, using a different factor for each livestock category (2,5).

Water hyacinth, considered a national pest infesting 3,250 km of Sudanese rivers and obstructing water flow, navigation, fishing and irrigation, is included in this assessment because of its good utilisation potential for biogas production. Laboratory and pilot plant trials have indicated that 400 to 750 m^3 of gas can be obtained from each MT of dry matter (9,10). To control its spread, 9 million MT of water hycinth (dry weight) are removed from the White Nile each year and burnt down to prevent re-infestation (1).

Agricultural residues were estimated using annual crop residue yield factors (in MT per unit cultivated area).

Since not all the biomass could be collected for biogas production, a collectability factor is assumed for each category, taking into account relevant factors such as the degree of confinement and the nomadic nature of some livestock owners. A collectability factor of 10% is assumed for sheep, goats and camels since those are largely owned by nomadic tribes. For cattle, 10% of which are in dairy farms, a factor of 20% is taken. A higher factor of 70% is assumed for poultry, being highly confined. Crop residues and aquatic weeds are easily collected. Collectability factors of 50% and 90% are taken for these categories respectively.

Applying these factors, the results indicate that 57.5 million MT of wastes and residues could be made available for biogas production each year. It should be noticed that this figure does not include organic wastes such as human wastes, municipal refuse, sewage sludge, food and dairy-processing plants wastes. Moreover, the factors applied are relatively on the low side compared with other published data (8,12). This final figure can therefore be judged as a conservative one in assessing the potential of biogas energy.

5. BIOGAS POTENTIAL

The amount of biogas produced by anaerobic digestion depends on the type of substrate used. Data reported in the literature vary according to the operating conditions such as temperature, loading rate, retention time, degree of mixing etc. A safe figure is estimated for each type of organic matter by analysing the vast amount of experimental data reported (2,3,5,6,13,14). Those figures are shown in Table 2 which also shows that 4.2 billion m^3 of biogas could be produced annually. This is equivalent to 8.8×10^{16} J/annum or 2.11 million TOE. Taking an efficiency of conversion for the gas of 60% (5), the useful energy that could be obtained is 1.266 million TOE.

By comparison with the rural household wood consumption for 1990 (0.98 mTOE), it can be concluded that biogas could totally replace firewood and charcoal as a source of energy for rural households. The environmental impact, as far as deforestation is concerned, will be significant, since 67.8 million m^3 of wood growing stock will be saved from cutting each year. This is equivalent to 68% of total annual wood cut.

6. PRACTICAL ASPECTS

From the practical viewpoint, a great and serious effort should be imparted by the government of Sudan to disseminate biogas technology on a wide scale in rural areas of the country. Institutional, training, manufacturing and financial facilities should be created solely for this purpose. Dissemination should be a slow process. If a biogas program is to be successful, careful preparatory work, alongwith good promotion and technical support is needed. It would be helpful to establish a National Biogas Centre to coordinate activities such as information collection and dissemination, research and development, design and standards, training, manufacturing or procurement of end-use appliances (stoves, lamps etc.), and to provide technical and financial assistance. The cost of building a family-size biogas unit in Sudan, including distribution and appliances, is around $1000 (7); this is beyond the reach of most rural households. Government loans to be repaid over a reasonable period will significantly help encourage people to switch to biogas with all the other benefits the owner will get (see section 2).

The experience of other developing countries, such as China, India, Egypt, etc., which proved the technical and economic feasibility of biogas family units (10 m^3 digester volume) and village or community-size units (50 to 75 m^3), could be drawn upon (2,5)

Another practical limitation is the limited availability of water in some parts of the country, although for most of the areas, where agriculture and livestock are concentrated, such a problem does not exist.

7. CONCLUSIONS

The production of biogas by anaerobic digestion of animal wastes, crop residues and aquatic weeds in family-size units, appears to offer a significant possibility for meeting the energy needs of the rural areas of Sudan. If proper steps are taken to spread the practice nationwide, wood and charcoal, the traditional sources of energy for rural population, could totally be replaced by a cheap, clean and efficient source of energy. The availability of local resources, generally wastes, which can be transferred into useful energy on a decentralized level is a definite benefit. Additional benefits are better health, better sanitation and better crops utilising the effluent as a fertilizer and soil conditioner. More important is the impact on the environment as a result of forest and bush vegetation conservation. Based on this argument alone, the development and subsidy of biogas plants could be justified, since the ecological and social effect of deforestation is so high that it justifies any amount of cost involved.

TABLE (1)

PROJECTION OF ENERGY CONSUMPTION IN SUDAN FOR THE YEAR 1990
'000 TOE

Sector	Hydropower	Pet.Prod.	Biomass	Total
Industry	42.0	456.1	428.9	927.0
Transport	0.0	826.3	0.0	826.3
Agriculture	13.7	127.8	0.0	141.5
Goverment	19.1	455.6	122.2	596.9
Household	45.2	121.4	7609.7	7776.3
TOTAL	120.0	1987.2	8160.8	10268.0

TABLE (2)

ANIMAL WASTES, CROP RESIDUES AND AQUATIC WEEDS FOR BIOGAS PRODUCTION AND AMOUNTS OF ENERGY PRODUCED
Base Year 1990

Sourc	Quantity million	Man./Anim. MT/yr	Resid./yr mMT/yr	C.F.	Residue Av. mMT/yr	Bio. F. cu.m/MT	Bio. Prod. m cu.m/yr	Energy m MJ/yr	TOE '000
Cattle	21.9	5.98	130.96	0.2	26.192	40	1047.70	22001.62	526.4
Sheep	21.7	1.10	23.87	0.1	2.387	40	95.48	2005.08	48.0
Goats	15.5	1.10	17.05	0.1	1.705	40	68.20	1432.20	34.3
Camel	3.2	3.65	11.68	0.1	1.168	40	46.72	981.12	23.5
Poultry	25.4	0.03	0.84	0.7	0.587	63	36.96	776.26	18.6
Total	87.7		184.40		32.039		1295.06	27196.27	650.6
Crop Residue			34.70	0.5	17.350	100	1735.00	36435.00	871.7
Water Hyacinth			9.00	0.9	8.100	145	1174.50	24664.50	590.1
GRAND TOTAL			228.10		57.489		4204.56	88295.77	2112.3

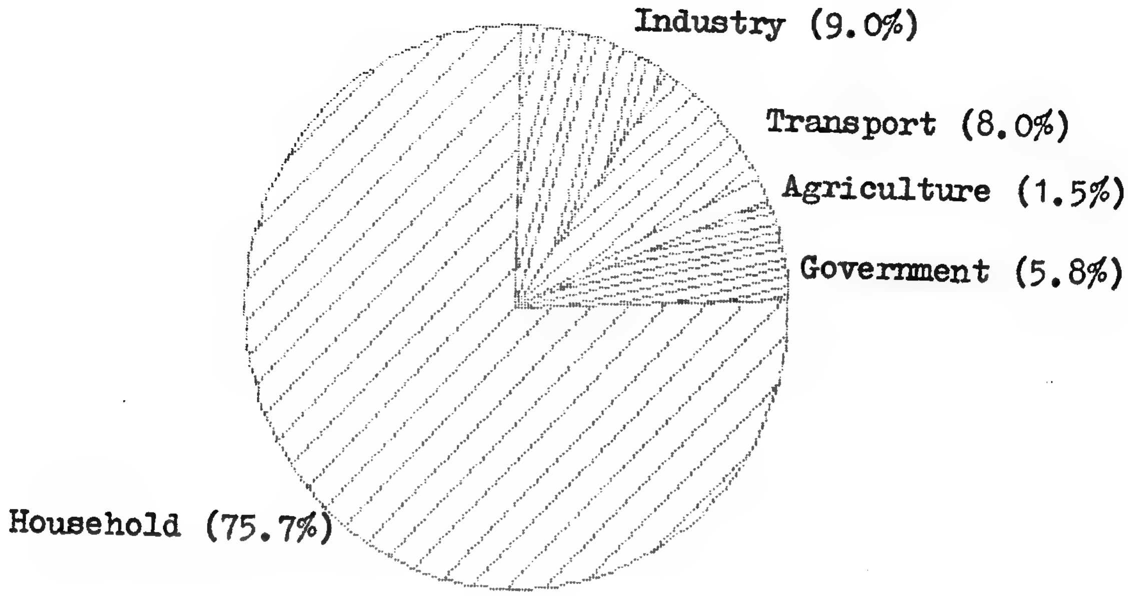

FIGURE (1)
ENERGY CONSUMPTION BY SECTOR (1990)

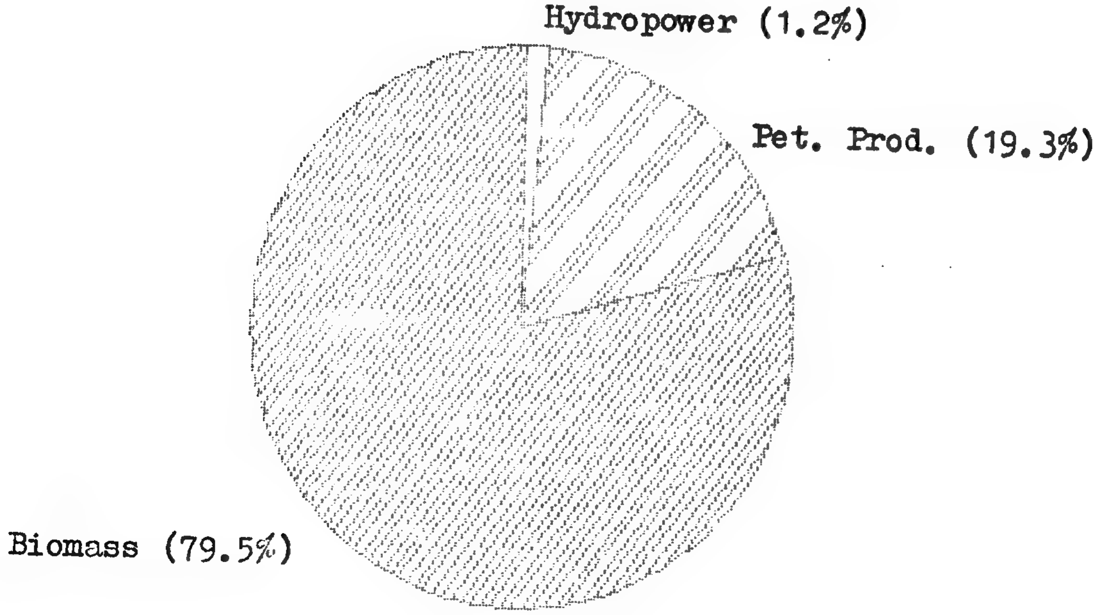

FIGURE (2)
ENERGY CONSUMPTION BY RESOURCE (1990)

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SECTION XVIII

RENEWABLE ENERGY APPLICATIONS

ELECTRICITY GENERATION BY SOLAR AND WIND ENERGY IN DEVELOPING COUNTRIES

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ABSTRACT

The use of solar and wind energy for electricity generation has shown through the last few years, considerable progress through the research work conducted in different aspects of this field and the experience gained in some applications of proposed systems, although several important and pronounced difficulties, both technical and economical have yet to be overcome.

In developing countries and in particular for those with ample solar radiation levels and adequate wind velocities encouraging the search for solar and wind applications, there are beside the mentioned problems additional considerations to be given to other related aspects, including problems of adoption of the new technologies with less developed industrial and technical infrastructure, problems associated with the usually weak and small electric grid, as well as training and qualifying the needed personnel.

This paper reviews briefly the development in electrical power generation by solar and wind energies and adresses the prospects of their application in developing countries with due regard to the related problems and suggests solutions to cope with these difficulties.

1. INTRODUCTION

The renewed interest in wind and solar energies in the last few years has called for diversified research work to investigate the different associated issues with these forms of renewable energy sources that have been known to man since the ancient ages in some form or the other.

The relative attractiveness of these sources besides being renewable and abundant lies in their relatively negligible running costs, minimum environmental impact as well as simple operation and maintenance.

Solar electricity generation has been realized by both central reservoir systems and distributed collector (photovoltaic) systems with relatively low unit size (KW range) and low overall efficiency (around 18%). Several countries have been engaged in extensive research and experimental as well as some practical application of solar electricity generation including Japan, USA, Canada, India, Spain and many others. The installed cost per KWp has shown a moderately decreasing trend, which while being encouraging for such projects, has given the possible customers the reasonable option of waiting for lower costs to be realized and hence postponment of installation of such projects,creating the difficult situation for the manufacturer of too few orders being placed besides the demonstration projects. As for the wind energy, both horizontal and vertical axis generator with two or more blades have been implemented in different parts of the world to generate electric power directly from wind energy in several countries including Denmark, Sweeden, The Netherlands, USA, Australia and others although the collected data of their technical and economical performance has yet to be enhanced and analyzed to produce reliable results with the different variables encountered.

The dependence of both solar and wind energy on weather conditions has created a lot of concern and interest in energy storage systems and the availability of some back-up system with due regard to load management. The need for such systems together with the dc/ac **conversion** arrangements contribute considerably to the high initial cost of these system.

The relatively extensive use of land per unit of generated energy both for solar panels or reflectors and wind machines could be prohibitive at certain locations. This is to be added to the little concern of the risk of possible flying objects from wind towers and the interference with the nearby communication systems.

The conversion from direct to alternating currents (dc to ac) envolves non linear system producing harmonics in the voltage waves that have to be carefully considered particularly when integrating the system with the conventional electric grid.

The economical size of the solar and wind plants has to be decided with due consideration to the solar radiation levels and wind velocities available.

2. SOLAR AND WIND ENERGY APPLICATIONS IN DEVELOPING COUNTRIES:

Most of the studies for the practical application of solar and wind energy in electricity generation call for small scale systems particularly at remote areas isolated from the electric grid such as small communities, remote communication facilities, small farming applications, water pumping, street and tunnels lighting. Such applications find its greatest potential in developing countries with ample solar radiation levels and adequate wind velocities and scattered scarsely populated areas far from the main cities.

Several examples can be cited of such actual applications although the operational records of these facilities, their technical performance, availability, efficiency, operation and maintenance records, economical status are in most cases lacking or not available yet. While developing countries provide the potentially favorable conditions for constructing such projects, they have generally additional problems to overcome before the successful harnessing of solar and wind energies in electricity generation, these include the relatively low level of industrialization and technical know-how and hence the need for foreign technical aid and equipment import. The difficulty in using the small grid as a back up system or in connecting the solar or wind generating power plants with the weak grid that may exist. However a small scale solar or wind plant for electricity generation at suitable location to serve a relatively light loads remote from the grid with adequate storage system could prove tc be ideal for such situations.

3. Electrical Power In Libya:

As an example of this consideration, Libya an oil producing country with an electric grid covering most of the relatively highly populated areas and farming regions along the coast cities and oasis with an extensive system of interconnected steam power plants and some diesel and gas units covering the base and peaking loads. The population are mainly distributed along these regions already served by the general grid. However there are several regions where the too small communities and the far distances separating them from the main grid prohibit the construction of very long lightly loaded transmission lines. In such communities and for other applications e.g. communication posts, meteorological stations etc. a system of wind or solar plant can be considered as a source of the needed electrical power. Fig. (1) shows the population distribution on the Jamahiriya map as well as the regions supplied by electrical energy from the electric grid or local generation stations. It also indicates the possible areas of interest for such projects, as populated regions with no electrical power supply.

4. SOLAR AND WIND ENERGIES FOR ELECTRICITY GENERATION IN LIBYA:

Through the research work (1), (2), (5) conducted previously it has been established that the average solar radiation levels and the wind velocities available in Libya are as shown in Figs. (2) & (3) respectively. With an average wind velocity of (29-12) Km/hr. prevailing in the areas indicated and an average annual solar radiation levels of 5.7 $KWh/m^2/day$ corresponding to 9 hrs. of sunshine per day.

The regions indicated 1, 2,...are proposed here for possible solar energy projects and the regions 5, 6,... for wind power projects outlined below.

. PROPOSED SOLAR AND WIND SYSTEMS:

Adopting small size projects could serve as pilots plants for generation of electrical power as well as for research work including performance data collection and analysis.

Typical proposed systems are to suit the existing local conditions, wind velocities and solar radiation levels.

PRELIMINARY ECONOMICAL CONSIDERATIONS:

Most of the literature indicate that the electrical energy generated both by solar and wind energies are far from being cost competitive with that produced conventionally in terms of LD/KW hr. Although most of these conclusions are based on estimates and assumptions rather than actual performance data that needs long time to establish and stabilize.

As for the proposed systems the main assumptions and results are outlined in Table (1) and (2), for the solar and wind systems respectively.

Table 1: Preliminary Economical Considerations of the Proposed Solar Energy System*

Installed Capacity/Unit	240 W
Initial cost/Wp	5.0 L.D*
Operation & Maintenance cost/annum	2%
Average availability of total capacity.	70%
Economical Life	20 Years
Average working hours/day	10
Annual charges on the capital investment	10%
Energy Production cost /Kwhr.	0.27 L.D.

*The system consists of a solar array, storage battery & battery charger, connections and installation.

Table 2: Preliminary Economical Considerations of the Proposed Wind Energy System

Installed Capacity	50 KW
Initial Cost/KW	450 L.D*
O & M cost/ann.	2%
Average availability of total capacity	10%
Economical life	20 Years
Annual charges on the capital investment	10%
Energy production cost	0.07 L.D/KW

*Libyan Dinar (L.D) = $ 3.3

An installed cost of LD 5.0/Wp is assumed for the solar system and 450 LD/KWp for the wind system. With energy production costs of 0.27 LD/KWh for the solar and 0.07 LD/KW hr for the wind systems.

It is to be emphasized here that these figures are indicative values that need to be refined with actual performance data.

5. CONCLUSION

Wind and solar generated electricity when adequately planned could meet the demand in carefully selected areas in developing countries.

Few, small size, remote and isolated projects with adequate storage system and maximum local participation seems to be the best option for exploiting the available renewable solar and wind energy in this field for these countries. Systems such as the proposed here may give a suitable start that need to be observed and further field studied.

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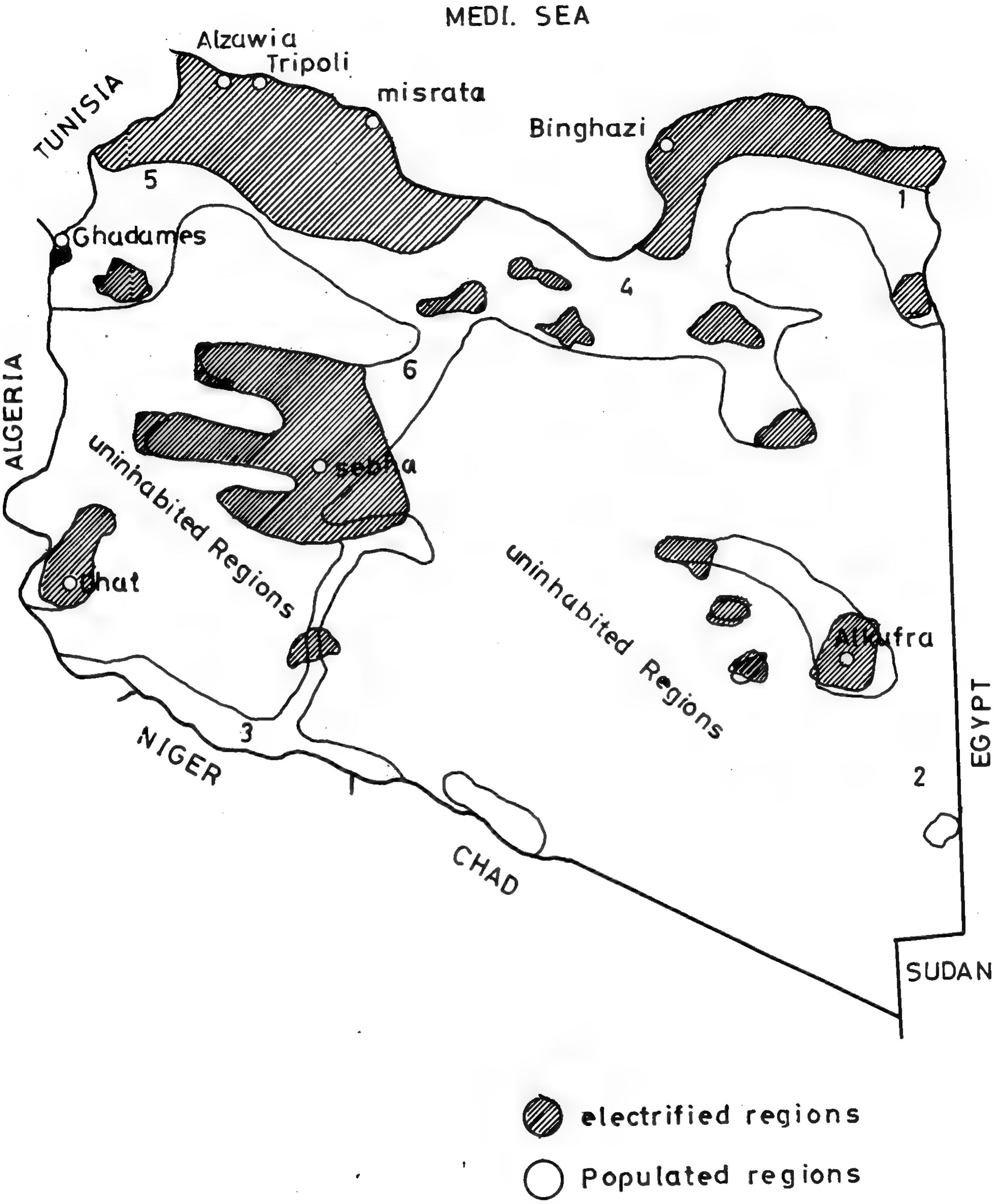

FIG.(1) POPULATION DISLRIBUTION AND ELECTRIED REGIONS

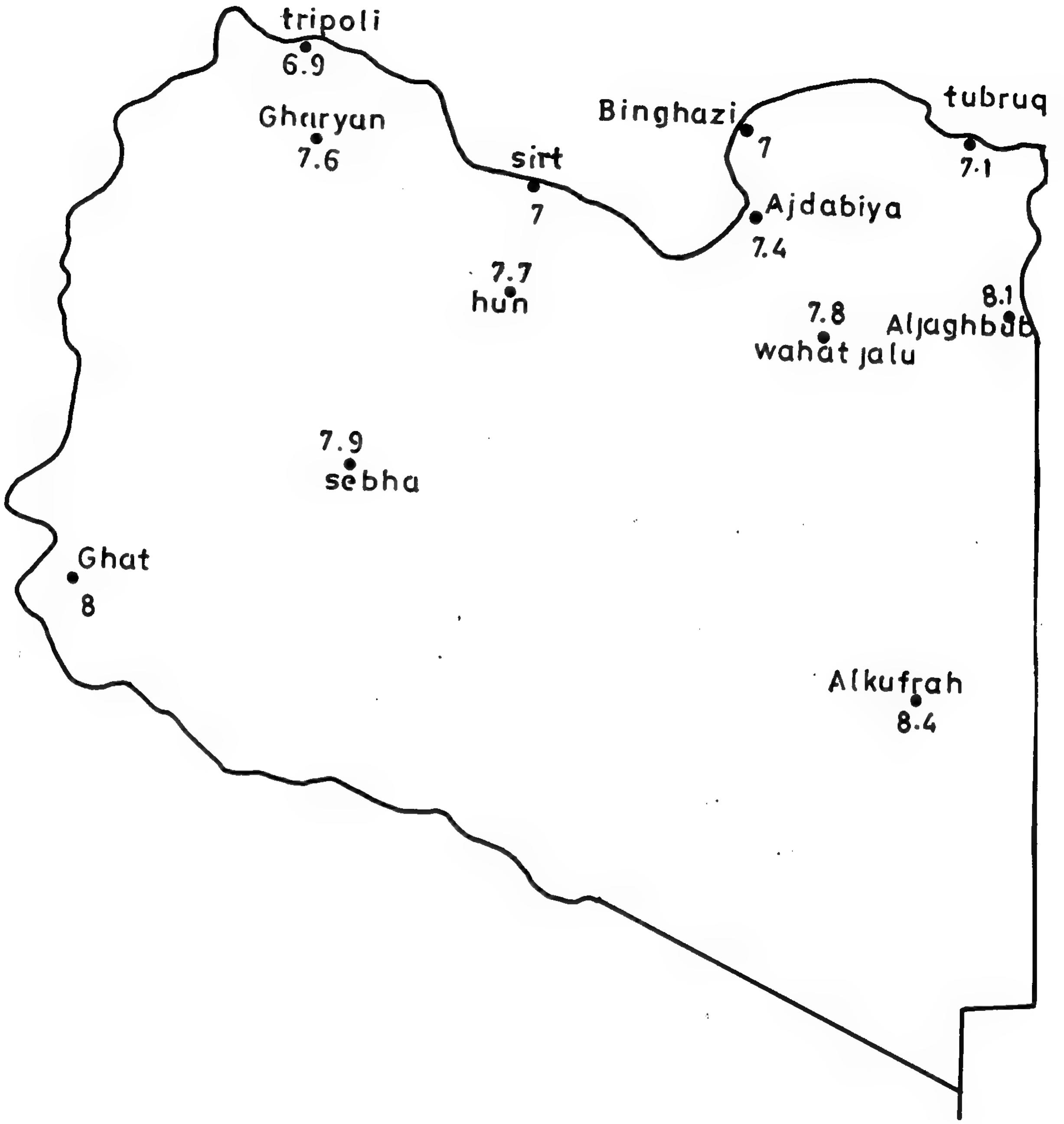

FIG.(2) SOLAR RADIATION LEV. IN LIBYA (MONTHLY AVERAGES OF DAILY SUNSHINE) (Kwh /m²/day)

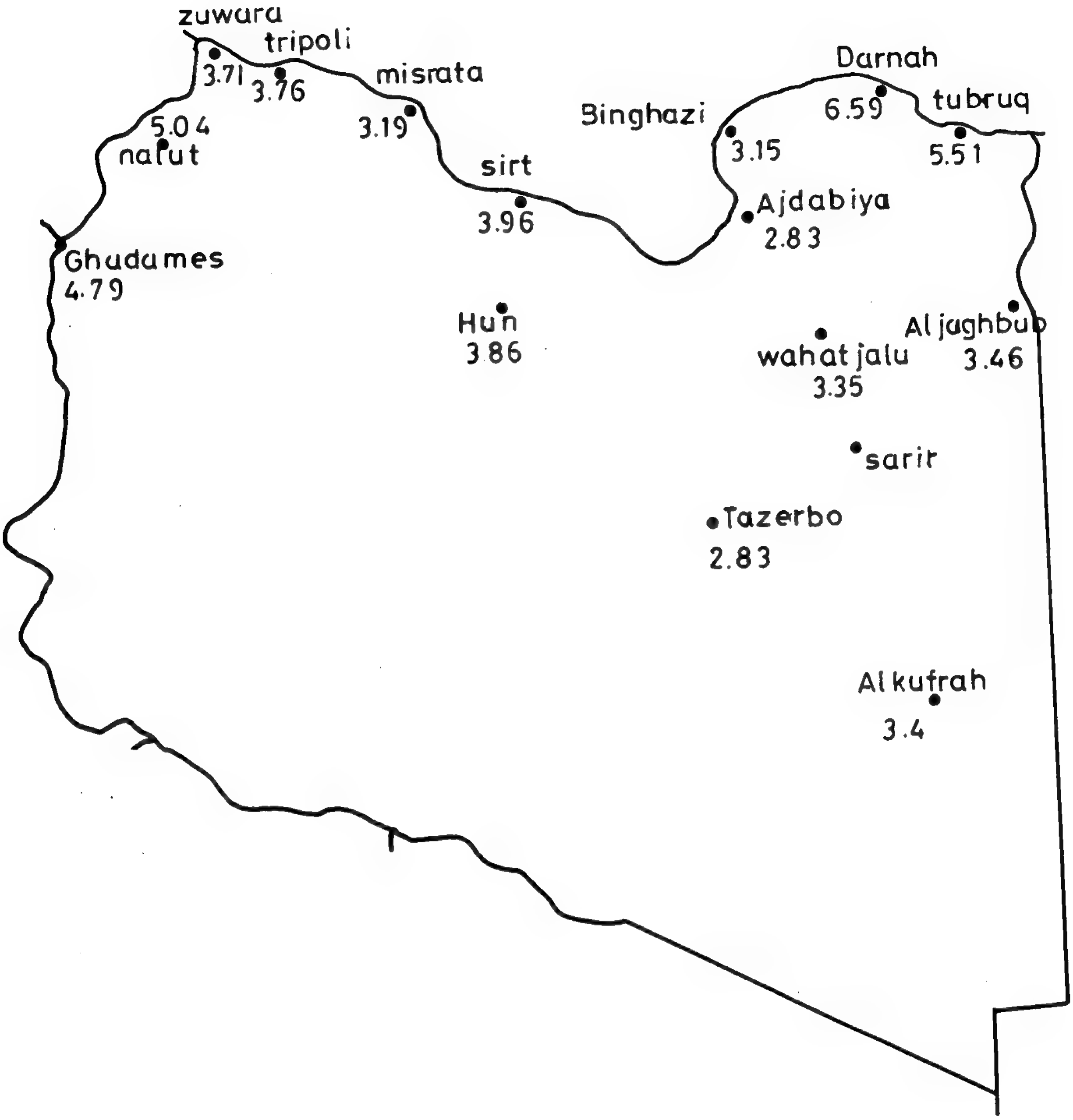

FIG. (3) AVERAGE ANNUAL WIND VELOIETIES IN LIBYA (m/s)

DESIGN AND TESTING OF AN OPTIMIZED WIND ELECTRIC PUMPING SYSTEM

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Abstract

A wind electric pumping system (5 m rotor diameter, 2 kW permanent magnet alternator, 20-30 m head multistage submersible pump) has been designed by means of an optimization numerical method and has been built and set up in a test field. The first experimental results are presented together with the theoretical approach.

1. Introduction

Conventional wind-pumping systems (that is: multibladed wind-mills mechanically driving reciprocating pumps) are very simple and cheap machines, and for this reason they are widespread all over the world. However, they show many limits when intensive wind energy exploitation is pursued:

a) they are not suitable for medium-high intensity winds, for both low efficiency and high stresses [1,2], and are suitable for low power and low water delivery only;
b) there is no water delivery during wind calms;
c) the machine must be set up upon the well;
d) stresses and mechanical failures increase with the water head.

These limits can be overcome or reduced by resorting to wind electric pumping systems (WEPS) (that is: an aerogenerator electrically driving an electric centrifugal pump) the little higher cost of which is offset by many advantages:

a) suitability to medium-high intensity winds and possibility of supplying higher powers and water flow rates;
b) possibility of electric storage and/or electric integration during wind calms, by means of electric diesel or network;
c) the eolic site can be chosen far from the well, so that the energetic criteria can be made independent from the higienic and practical ones;
d) the overall efficiency can be kept high in a wide wind intensity range;
e) the mechanical reliability is quite good;
f) the main components (generator and electric pump) can be found

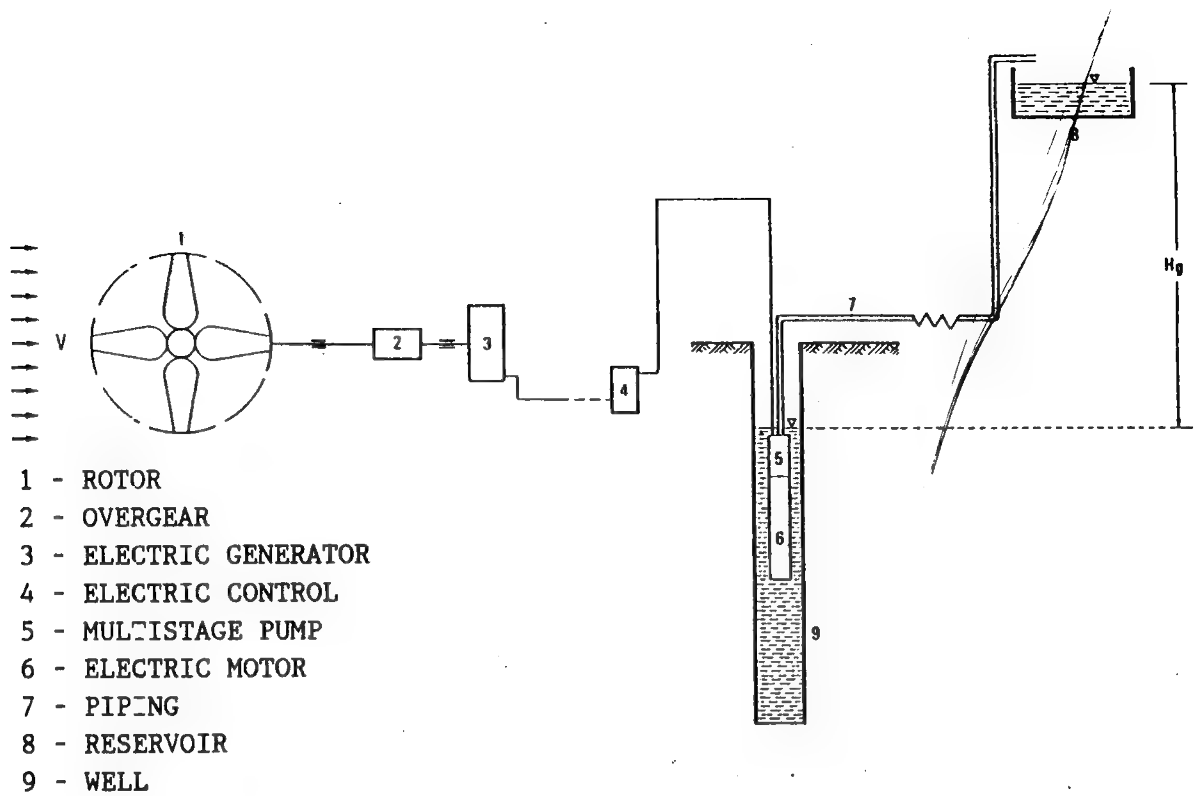

Fig. 1 - Scheme of the WEPS

commercially everywhere.

During the last years many WEPS applications have been realized and tested [3-8]. However, it seems that the actual performances are not always the best one could theoretically expect from the coupling between the cubic-law of the rotor optimum power and the quasi-cubic law of the pump required power. As this matching is very sensitive to the operating conditions, it is important to foresee them accurately and to make a correct choice of the proper pump. In this paper, a method for the optimized design of a WEPS is presented together with the first field tests od a 2 kW experimental model.

2. Theoretical model

The scheme of a WEPS is represented in Fig.1. A theoretical model of the performances of such a system in stationary conditions can be obtained when the performances of the wind rotor and of the pump are analitically expressed.

The rated power at the rotor shaft is:

$$P_r = 1/8\ \rho\ c_p\ \pi D^2\ V^3 = 0.48\ c_p\ D^2\ V^3 \quad (W) \tag{1}$$

when the air density at 15°C, 760 mmHg is assumed. When introducing the experimental law $c_p(\lambda)$, eq.(1) allows to draw up the available power curve $P_r(N_r,V)$ (Fig.2). The maximum-power (optimum) line of this diagram has a purely cubic-law, both in frontal wind or in yaw; this line must be approached by the load if the best rotor efficiency has to be obtained.

As we are interested to realize only simple, cheep and reliable systems, only fixed-blade rotors of the CWD type [9,10] have been considered in our

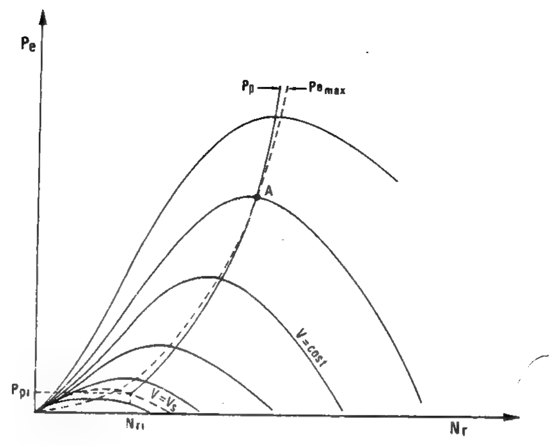

Fig. 2 - Power curves of a WEPS

study; however, the method can be applied to any wind turbine the $c_p(\lambda)$ law of which is known.

The required power curves of a centrifugal pump at varying speed can be obtained when the characteristic curves $H^*(Q^*)$ and $\eta_p(Q^*)$ at the standard speed N_p^* are known and the hydraulic similitude law is applied:

$$H = z\,H^*(N_p/N_p^*)^2 \quad ; \quad Q = Q^*\,N_p/N_p^* \quad ; \qquad (2)$$
$$P_p = z\,P_p^*(N_p/N_p^*)^3 \quad ; \quad \eta_p = \eta_p^*$$

and the required mechanical power is:

$$P_p\,(W) = Q\,H/6.12\,\eta_p \qquad (3)$$

where Q is in liters/min and H in meters.

The pump head and the water flow rate are also bound by the load law of the hydraulic plant, that is:

$$H = H_g + k\,Q^2 \qquad (4)$$

A number of KSB single-stage ground pumps and ATURIA multistage submersible pumps have been examined in the present work, before choosing two proper submersible pumps.

When eq.(4) is associated to eqs.(2) and (3), the load power law $P_p(N_p)$ can be obtained numerically, and the law $P_p(N_r)$ can be obtained by the overall speed ratio $\tau = N_p/N_r$. Being $\eta_t = \eta_m\,\eta_a\,\eta_{mp}$ the overall efficiency of the power transmission, the available power at the pump shaft is: $P_a = \eta_t P_r$. In our procedure, constant values of the efficiencies have been considered and an overall value of $\eta_t = 0.4$ was assumed. As regards to the overall speed ratio, it would take into account the slip of the electric motor; however, as no measurement nor data were available during design, no slip has been introduced in the computations.

In **Fig.3** both the available power $P_a(N_r,V)$ and the required power $P_p(N_r)$ have been plotted for a two-blade CWD wind-rotor (steel-plate rotor N.6 of Ref.[9]), 5 m diameter, and for one 20 and one 40-stages submersible pumpset ATURIA AS24. The overall speed ratio is 18. This diagram is the final result of a numerical optimization which is obtained by means of trials that are checked graphically in order to get the power load curve $P_p(N_r)$ close as possible to the optimum available power line $P_a(N_r)_{opt}$. This optimization can be obtained by choosing the appropriate rotor and pump types, and by

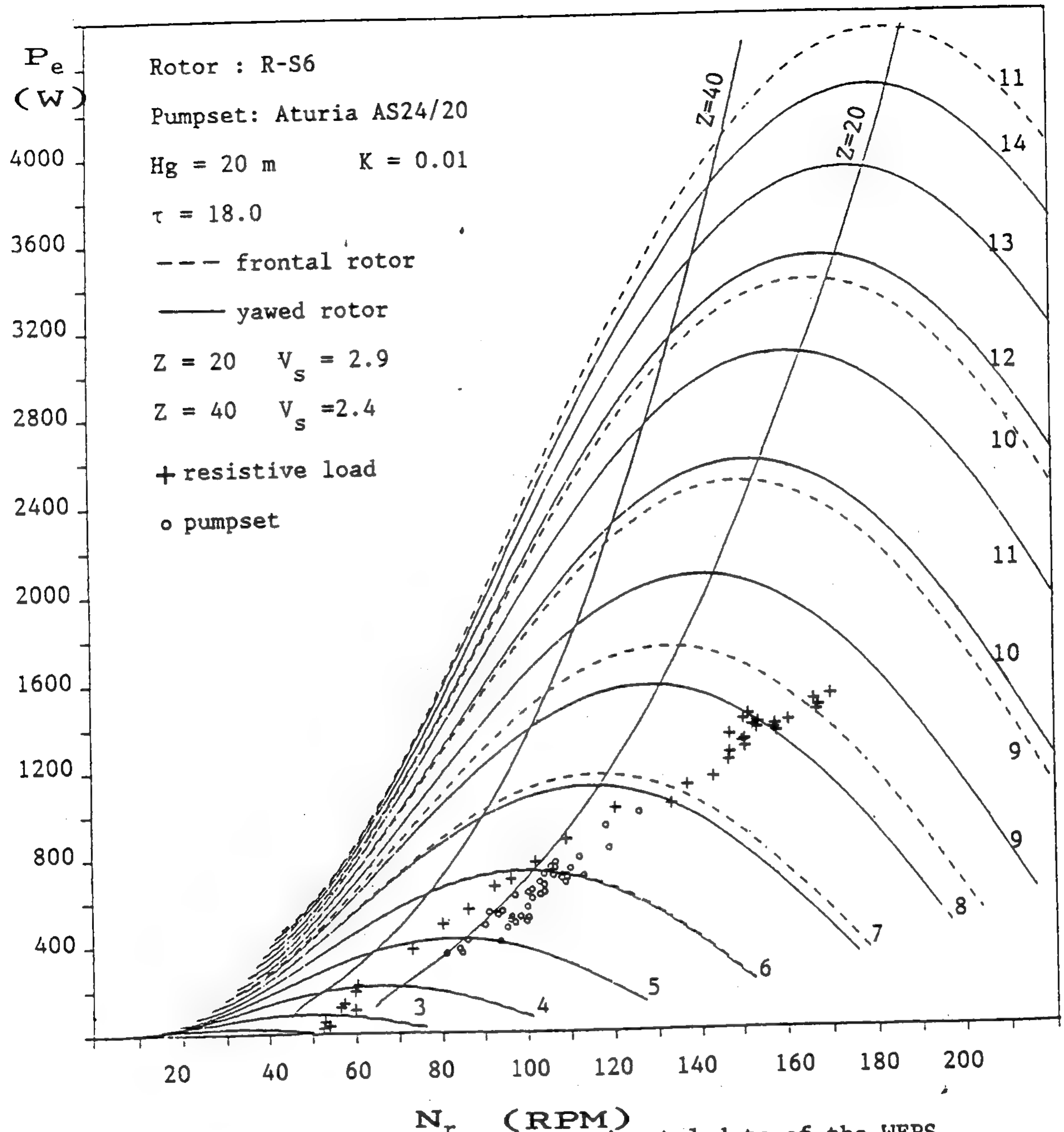

Fig 3 - Theoretical curves and experimental data of the WEPS

changing some free parameters, that is: rotor diameter, overall speed ratio, stage number and, within certain limits, the loss coefficient k.

As the wind machine we considered gets speed control by yawing the rotor by means of one fixed and one hinged vane (**Figs. 4 and 5**), a correction of the available power is needed and can be obtained by solving the equilibrium equations of the motor swinging system under the aerodynamic and the mechanical forces [11]. The yaw angle ϕ is obtained as a function of the wind speed and the wind component $V\cos\phi$ is considered instead of V. In **Fig.3** both the frontal-rotor and the yawed rotor power curves are shown.

The system starting speed V_s - that is: the wind speed at which the water delivery begins - can be calculated when the shut-off pump head H^*_s and power P^*_{ps} are known and the required power is equated to the available power at the starting speed V_s. The resulting equation:

$$c_{ps} = (60\ \tau\ /\ \pi\ D\ )^3\ \ (z\ P^*_{ps}\ /0.48\ \ \ \eta_{ts}\ D^2\ \ N^{*3}_p\ )\ \ \lambda^3_s \qquad (5)$$

associated to the law $c_p(\lambda)$, gives the required starting values c_{ps} and λ_s, while the starting speed is given by:

$$V_s\ =\ (\ \pi\ D\ N^*_p\ \ /60\ \tau\ \ \lambda_s)(H_g\ \ /z\ H^*_s\ )^{\frac{1}{2}} \qquad (6)$$

As it can be seen, V_s decreases when z increases, therefore a high number of stages would be required if a low starting speed is needed at high water elevation H_g. This means that the choice of z must take into account not only the optimum matching needs but also the starting problem, that requires a stage number which is always too high for the optimum coupling. From this result, it seems to be suitable if two different pumpsets are driven during starting and during stable water delivery: the first set (booster) must have a larger number of stages than the main set and must operate automatically and alternatively to the main one. In **Fig.3** the load curves of a 20-stage and of a 40-stage pump are showed, and the related starting speeds are indicated for H = 20 m (a stronger advantage of the 40-stage appears for higher H_g, according to eq.6.).

3. Description of the WEPS

The main features of the WEPS described in the present paper are:

- possibility of construction and/or repairing in developing countries;
- reliability and independence from conventional energy sources;
- optimization of the system to get the best efficiency of each component (wind rotor, alternator, pump);
- good intensity design winds: 6 m/s and higher.
- water flow rates of about 20 mc/day under 20-30 m of water elevation.

By means of the previously described method, the main components have been defined and the WEPS has been built in Italy. Its components are: wind rotor, belt drive, alternator, pile, electric cable, electric submersible pump.

The 5 m diameter wind rotor (**Fig.4**) has two fixed pitch, curved steelplate blades (CWD rotor, defined as the N.6 steelplate rotor in Ref.[9]), with a tested optimum tip-speed ratio $\lambda = 4.25$. These profiles have been chosen as they are very easy to built, although they have a drag-lift coefficient only slightly lower than a NACA profile at the same Reynolds number. Rotational speed control is obtained by wind motor orientation operated by one fixed and one hinged vane (**Fig.5**). Besides, in this experimental model a safety electromagnetic brake is mounted on the rotor shaft.

The cog-belt drive between alternator and rotor shafts has a 1.5 speed ratio; this kind of drive has been chosen because its reliability and cheapness .

The generator is a three-phase, permanent ferrite magnet alternator, with 12 pair of poles, that gives 2 kW at 60 Hz. It was expecially designed and built [11]. The p.m. alternator was chosen for its high efficiency in a wide range and because it doesn't need excitation, this allowing to analyze and test the starting of the system under hydro-mechanical load only.

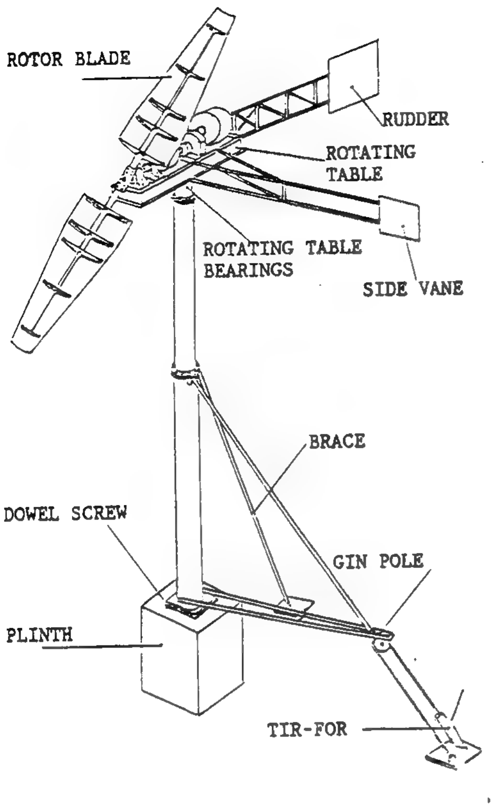

Fig. 4 - Artist view

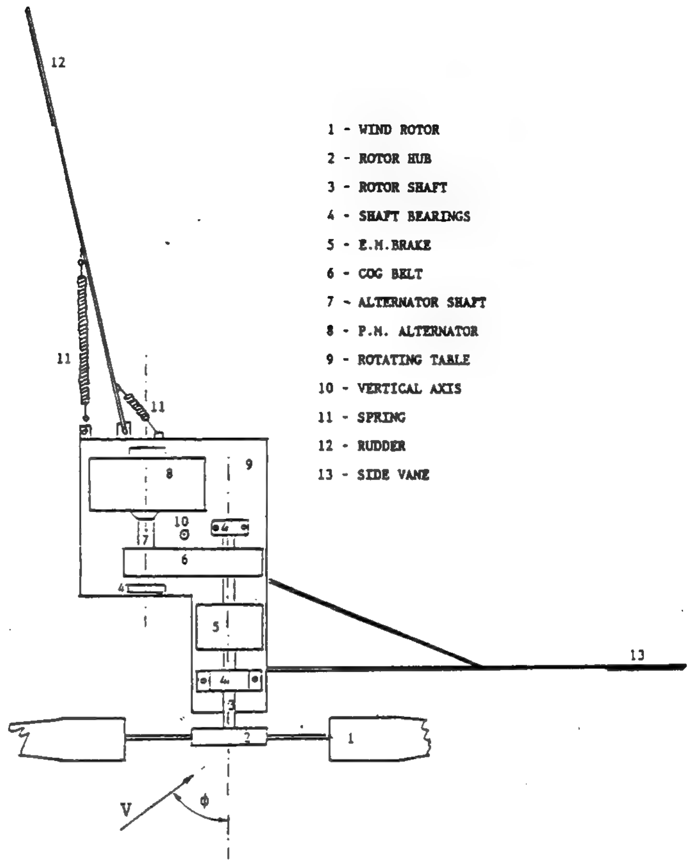

Fig. 5 - Scheme of the motor

As a 12-speed ratio is ideally (i.e. without slip) established between the the single-pole electric pump shaft and the generator shaft, the overall speed ratio between pump and rotor shafts is (ideally) 18. A definitive model of the WEPS will be realized with a commercial 2-poles alternator and a 9-speed ratio gear box.

The unipolar motor of the pump is fed in the frequency range 20-66 Hz: the lower frequency depends on the safety limits of the motor, while the higher one depends on the mechanical safety limit (4000 RPM) of the pump. The pumpsets that have been considered are two 20-stage ATURIA AS24, to work together in series only during starting; the main pump (driven by an higher powerfull motor, suitable to run up to 4000 RPM) works in all the operative range, while the other one (with a standard motor) has to work during starting only and to be shut-off automatically at higher wind speed. A new, more efficient pumpset model (ATURIA AP4D) is intended to be tested too.

Finally, the pile is a 9 m high steel tube, hinged at the base to allow its lifting by a tir-for.

4. Experimental set-up and preliminary test

The aerogenerator has been set-up in the test field of the University of Calabria (**Fig.6**), together with an hydraulic loop where different hydraulic

Fig. 6 - The Test Field

load curves could be simulated. The water elevation was set at the selected values by an automatic pressure control valve, while pressure losses could be changed by a gate valve.

The 10'-average value of wind speed at 10 m of elevation, alternator RPM, electric power, water flow rate and pump head were measured. A first set of tests was carried out with a purely resistive load in a good wind intensity range (up to 8.5 m/s), while unfortunately pumping tests took place during a period where only a narrow wind range could be explored (from about 6 to 7.5 m/s). Therefore the results that are presented here must be considered as a very limited test; they are shown in this paper as first results to be expanded by additional measuraments. No failures happened till now; however, because of the limited range of wind speed during a limited working period, the reliability of the machine has to be still checked.

In **Fig.3** the measured electric power P_e is plotted against the rotor speed N_r, together with the theoretical available power curves of the rotor (in frontal and yawed configuration) and with the theoretical required power curves of the 20 and 40-stage pumpsets.

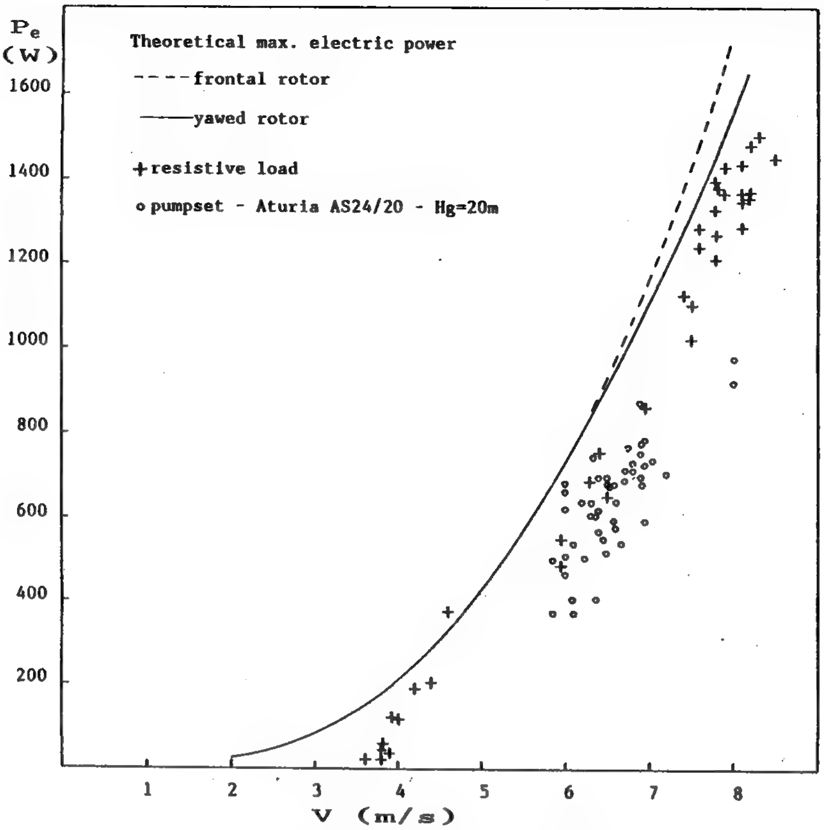

Fig. 7 - Electric power versus wind speed

Being the generator voltage about proportional to its frequency, the resistive load law is near a parabole; therefore it doesn't follow the cubic law of the optimum available power: this test was carried out in order to check the appropriate performances of the aerogenerator.

The experimental results of the pump tests show sufficient agreement with the prevision in the limited wind range that was possible to investigate. Tests were carried out with different pressure loss coefficients, k; however, the results seem to be insensitive to k.

In Fig.7 the measured electric power is plotted against the wind speed, V, together with the optimum available power curves for frontal and yawed rotor (the first one is practically coincident with the theoretical pump load curve, as it can be seen from Fig.3). The data scattering and the deviation from the theoretical line in this figure are stronger than in Fig.3. When considering the resistive tests, it can be remarked that the electric power at the wind speed of about 6 m/s (design wind speed) in Fig.7 is lower than the optimum while it appears to be the same in Fig.3. This could be explained either with a lower c_p than the optimum one (due either to wrong tip-speed ratio or to uncorrect blade setting) or with a rotor yaw angle different from the designed one. The last could be the actual cause of the deviation, as in effect a commercial spring not corresponding to the required characteristics had to be used provisorily.

As regards to the pump data, their stronger deviation from the theoretical prevision is probably due to the motor slip, which was not possible to foresee and to mesure till now.

In Fig.8 the water flow rate is presented. Very few data can be shown here because of failure of the flowmeter during tests. The reduction of the flow rate in comparison with the design should have the same cause of the power reduction.

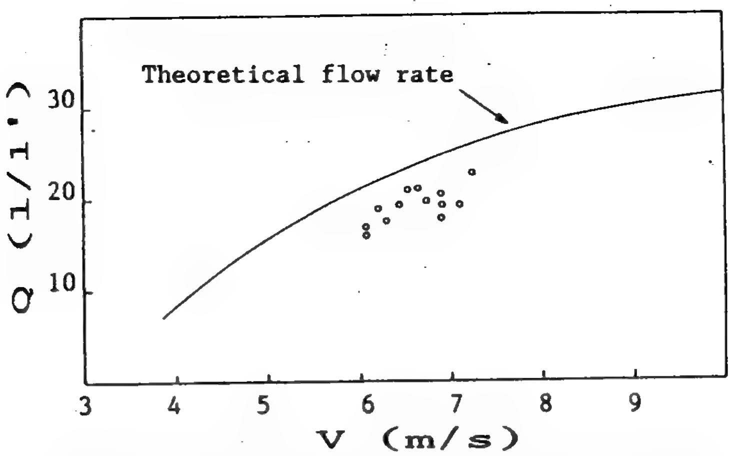

Fig. 8 - Water flow rate versus wind speed

5. Concluding remarks

After the first running and the preliminary tests of a WEPS made by a 5 m, two fixed-blades rotor, a 2 kW p.m. generator and a 20-stages electric submersible pumpset, the following remarks can be done about the troubles and the drawbacks that were encpuntered:

1) The test field of the University of Calabria, where the WEPS is being tested, is realized in a windy but remote site, far from the electric network; so the instrumentation has to be supplied by a motogenerator and the operator présence is needed (no automatic data aquisition was available). Therefore, the time needed to get a lot of data in a wide range of wind speeds is very long. No starting tests were possible to carry out till now.

2) Tests of the 40-stage pumpset have been not yet carried out.

3) The yaw angle and the pump speed were not yet measured as the instrumentation was uncompleted. The measurament of the yaw angle allows the knowledge of the actual value of the power curves to check the reliability of the design method and to improve performances; the determination of the pump speed is necessary to know the actual motor slip.

4) Tests with variable purely resistive load must be carried out to measure the available electric power at different alternator speeds in order to know the power curves in a sufficiently large range and to check the actual $c_p(\lambda)$ curve.

5) Although some difficulties and troubles need a period of tests and maybe the modification of some geometrical components of the yawing system, in order to improve and set-up the machine, the first field results show a sufficient agreement with the theoretical approach and convalidate the applied method.

List of symbols

c_p power coefficient
D rotor diameter, m
H water head, m

H_g water elevation, m
k pressure loss coefficient, m/(1/1')
N_p pump shaft speed, RPM
N_r rotor shaft speed, RPM
P_a available power at pump shaft, W
P_r rotor shaft power, W
P_e alternator electric power, W
P_p pump shaft required power, W
Q water flow rate, 1/1'
u rotor tip speed, m/s
V wind speed, m/s
z pump stages number
η_a alternator efficiency
η_m mechanical efficiency of the transmission
η_{mp} electric motor efficiency
η_t overall efficiency of the power transmission
λ tip-speed ratio = u/V
ρ air density
ϕ yaw angle

* indicates quantities of single-stage pumps at the standard speed N_p^*.
s indicates starting conditions of the water plant or shut-off condition of the pump.

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THE POTENTIAL AND APPLICATIONS OF RENEWABLE ENERGY IN JORDAN

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ABSTRACT

In this paper the energy demand in Jordan and the patterns of consumption are given and discussed.

Renewable energy resources in Jordan are presented, and an overall assessment is given to conclude that the most promising resources are solar and wind energies, being the most appropriate for application in remote and rural areas. The potential and application of these two resources are given together with their economical assessment. Finally the research and development activities in both fields are outlined.

1. INTRODUCTION

Jordan is a developing non-oil producing country which imports approximately all its needs of energy in the form of petroleum and its products. Jordan's total consumption of energy in 1987 amounted to 3 million tons of oil equivalent, showing an increase of 4.5% over 1986. The average annual growth rate of the GNP during the period 1985-1987 was about 3% which is approximately the same as the growth rate of the energy consumption. Thus the energy elasticity was one, down from 1.3 in the early 1970's to the early 1980's [1]. This trend reflects the more efficient use of energy. The cost of energy consumption in 1987 reached JD 132 million up from JD 104 million in 1986 [1]. This indicates the burden of the cost of energy on the national economy and the utmost significance of energy conservation policies and the urgent need for the country to develop and utilise its indigenous sources of energy in an appropriate, efficient and accelerated manner.

In this paper the potential and application of renewable sources of energy in Jordan are presented and discussed; and

the possibility of using them as substitutes for imported oil is given.

2. PATTERNS OF ENERGY CONSUMPTION IN JORDAN

The sectorial distribution of primary energy consumption percentage in Jordan for the year 1987 is shown in figure 1, from which it can be seen that transport sector is the main consumer as it consumes 38.8% of the total energy. It is therefore recommended to increase its efficiency and improve the transport management. On the other hand, table 1 shows stability in the energy consumption by this sector during the last three years, whereas the industrial sector shows an increase in consumption due to the growth in electricity generation. The household and others sectors show a moderate increase in consumption.

Table 1. Sectorial Distribution of Energy Consumption in Thousands toe

Sector / Year	Transport	Industry	House hold	Others*	Total Consumption
1980	865	353	366	218	1802
1985	1157	696	452	436	2741
1986	1185	.708	491	487	2871
1987	1164	835	507	495	3001

* Others includes: commercial, agricultural, water pumping, street lighting, government institutions, radio and T.V.

Electricity forms the second main consuming sector in Jordan. Its consumption amounted to 2655 GWh in the year 1987 (compared with 2323 GWh in 1986) representing 27% of the total energy consumption and an annual growth of 14.3%. The average annual growth rate during the last five years amounted to 16.2% [2]. Figure 2(a) gives the electricity consumption in GWh for the different sectors over the last five years. It can be seen that the industrial and domestic sectors are the main consumers of electrical energy and an increase in the growth rate of these sectors exists. Similarly, an increase in the growth rate of electricity consumption by the water pumping is indicated, whereas commercial, street lighting and others, indicate a very

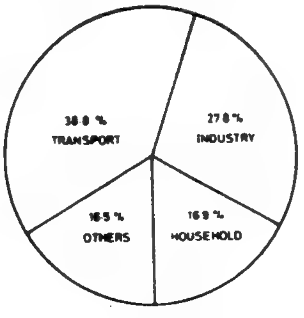

Fig.1. Sectorial Distribution of Primary Energy Consumption in Jordan, 1987.

moderate increase in electricity consumption , figure 2(b) gives the sectorial distribution of electrical energy consumption for the last year and table 2 gives the consumption of each sector in toe and as percentage of the total energy consumption.

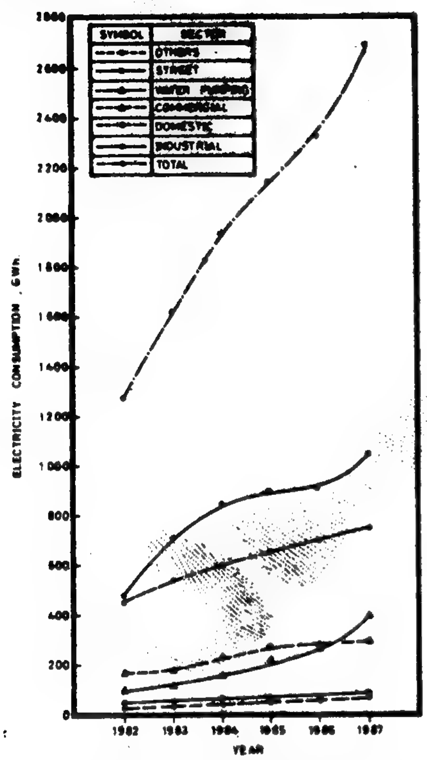

Fig.2(a) Sectorial Distribution of Electrical Consumption, 1982-1987.

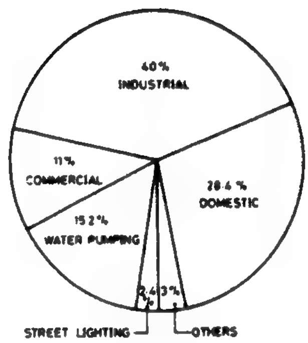

Fig.2(b) Distribution of Electricity consumption by sector, 1987.

Table 2. Energy Consumption by Each Sector

Sector	Energy consumption toe in 1000	% of the total energy consumption
Industry	324	10.8
Domestic	231	7.7
Water Pumping	123	4.1
Commercial	90	3
Street Lighting	18	0.6
Others	24	0.8

3. RENEWABLE SOURCES OF ENERGY IN JORDAN

3.1 Solar Energy

The average daily radiation intensity in Jordan is about $5.5 kWh/m^2$ for approximately 300 days per year [3]. Thus in one year the amount of solar energy reaching Jordan is about 13 billion toe which is four thousand times the total energy consumption. Solar energy applications in Jordan have a very wide spectrum which includes: water heating, space heating, water pumping, water desalination, electricity generation, green houses, crops drying, radio-telephone systems, solar

ponding for electrification and for potash recovery.

3.2 Wind Energy

Wind energy is not as abundant as solar energy. Most of Jordan's regions, are characterised by a low to medium wind regime with average wind speeds ranging from 3.6m/s to 5m/s, which is well suited for water pumping. In coastal and some other regions in the northern part of the country, the monthly average wind speed ranges from 3.6 - 7.4m/s with an average power density ranging from $105W/m^2$ to $470W/m^2$, which is suitable for power generation [4].

3.3 Biomass Energy

Relatively little information is available on biomass resources in Jordan. However, it is believed to be minimal and pertains to wood, animal wastes, crop residues and left-over food. The potential of using animal waste for biogas production is given in reference [5], which gives a total of 127,748,800 kWh that can be produced, which is equivalent to 31937 toe. This represents almost 1% of total consumption in Jordan. In reference [3], the ratio of the energy from fire wood to animal waste to crop residue can be calculated as 85.6:11.9:1.5. If fire wood is to be utilised, which is not advisable, then the total contribution of the biomass will amount to 10% of the total primary energy consumption to substitute imported oil in electricity generation, lighting, cooking and running agricultural motors.

3.4 Geothermal Energy

Geothermal resources exist in the form of hot spring at Al-Zarah with a surface temperature of 45^oC and at Zarqa Ma'in with a surface temperature of 63^oc. The combined hourly discharge of these springs into the Dead Sea is estimated to be 2000 m^3 [6] which represents 6780 toe per annum, a very negligible amount of the total energy consumption in Jordan. At present, the exploitation of geothermal resources is being carried out and it can be safely said that a long time is needed before this resource can play an appreciable role in energy supply in Jordan.

3.5 Hydropower Energy

Water resources for power generation require continuous flow of water that falls from high altitude. Examination of water resources data in Jordan reveals that most of Jordan's dams lack these criteria, they are either dry in summer or water falls from a low attitude. Therefore, Jordan's hydropower potential is limited to about 25MW of which 5MW is at the King Talal Dam and 20MW at the Maqarin Dam near the Syrian borders [6]. As it can be seen, this forms a negligible percentage of the total energy consumption in Jordan.

Examination of these renewable resources indicates that the most promising among them are mainly the solar and wind

resources and their present activities in Jordan will be discussed in the following section.

4. POTENTIAL AND APPLICATIONS OF SOLAR AND WIND ENERGIES IN JORDAN

4.1 General

The fact that solar and wind energy is a dilute form of energy makes it most applicable to a decentralised mode of energy consumption, well suited to remote and rural areas. Despite their simplicity, good reliability and non-polluting nature, the following obstacles preclude their widespread utilisation:

i) Non-continuous availability and the variation of intensity with time.
ii) The low efficiency of conversion systems.
iii) The high initial cost of the conversion system.

Summary of the applications and activities on solar and wind technologies of these institutions is given in the following sections.

4.2 Water Heating

The use of solar water heaters SWH started in Jordan in the early 1970's, ever since the total number of SWH installed in houses at the end of 1987 reached 100,000 units [7]. This value represent a 27% penetration rate. This represents an annual energy saving of 2500kWh per unit. If an overall conversion efficiency of 32% is assumed then total savings are equivalent to 62500 toe i.e. 2.1% of the total fuel consumption or 7.7% of the electrical energy consumption.

On the large scale and industrial level, the Royal Scientific Society, RSS, in collaboration with UNIDO are setting an SWH pilot project to provide the energy required in heating water for a dairy factory. Another project involves supplying a hotel in Aqaba with solar heated water.

Summing up, if solar water heating is effectively used in all the consuming sectors this will cause a total saving of 6.7% of the total energy consumption. This figure is given by the Ministry of Energy and Mineral Resources of Jordan.

4.3 Water Pumping

Jordan has water wells possessing a variety of depths and a variety of yields [6,8]. Examination of the data related to these wells reveals that water pumping from them can be carried out by solar or wind energy technologies. At present, wind energy is used for pumping water from five of these wells: three of them are using mechanical pumps and two electrical pumps. The different wind energy systems used for water pumping and the advantages and disadvantages of each system are given in reference 8.

Photovolatic, PV, systems are also used in Jordan for water pumping from five wells. Two identical systems were built at Umari and Jafir, where it was found that the cost of $1m^3$ pumped by the PV system is only 0.6 of the cost of $1m^3$ pumped by diesel [9].

On the whole, it can be concluded that apart from the socio-economic benefits of supplying the water needed for domestic use and irrigation using solar and wind energy systems, they have proved to be reliable and cost effective. If the energy consumed by water pumping can be supplied by solar or wind technology then the overall energy saving will be 123000tce i.e. 4.1% of the total energy consumption.

4.4 Electricity Generation

Electrification in Jordan is being extended at a very high rate. The great majority (about 94.6%) of the rural population in Jordan have already been connected to the national grid [2]. However, the use of solar and wind energy for generating electricity has a great importance because it can alleviate the load on the national grid and save from the primary fuel consumption. The following wind, solar and combined wind/solar energy projected were erected:

i) A new pilot project, using wind energy conversion systems to generate electricity, to be connected to the national grid, is under construction at Al-Ibrahimiya near Ras Muneef in the northern part of Jordan. The project consists of four wind turbines generating 80kW. It is interesting to note that the maximum wind speed in this area coincides with the peak demand for electricity and therefore, makes the use of such a system highly economical. Nearly 15% of the peak load is expected to be supplied by wind energy conversion system i.e. 125MW. The feasibility study of the above mentioned pilot plant shows that the cost of unit energy wind (kWh) is 50% less than that of the electricity unit (kWh) provided by the national grid [10].

ii) PV systems were used in different projects, these include:

a) The supply of five repeater stations which belong to the civil defence and police. Each system consists of 160 Wp PV generator, charge regulator, and a storage battery of 240 Ah at 12 volts. The total energy needed for each of the stations is 460 Wh.

b) About 100 PV units (each with a power rating of 40 W) for powering radio-telephones were installed at rural and remote areas and along the desert roads in Jordan. The units have proved to be efficient, reliable and a cheap method of communication.

c) Individual application of PV systems were used in remote and isolated areas in Jordan to meet basic electricity needs such as: clinic refrigerators, electric lighting, education television and emergency telephone.

iii) Another project for providing electricity to a remote village "Jurf Al-Daraweesh" 170 km south of Amman, uses the hybrid wind-PV system. The system consists of a PV generator of 10 kWp capacity, a wind generator of 40kW capacity and a storage system of 300 batteries (100 Ah at 12 volts each) connected together to build 220 volt DC blocks [11].

4.5 Other Applications

i) The area cultivated in green houses increased from 50 acres in 1970 to over 2000 Acres at present. The potential of using solar energy in the agricultural sector still exists for green houses and drying crops and their sterilization.

ii) Another application of solar energy is the evaporation ponds for potash recovery as solar energy is used to recover about 1.2 million tons per year of potash and other by-products from three evaporation ponds with a total area of 76 km^2. The total solar energy utilised in this process is estimated to be 3.21×10^{13} kcal per year[6], which is equivalent to 3.1Mtoe, i.e. 103% of the total energy consumption in Jordan.

iii) A testing laboratory using a solar simulator was built by the RSS for testing four solar collectors simultaneously. Based on the data from this project, work is being carried out at present to classify the solar collectors manufactured by the local companies and put down the engineering design for the most appropriate and efficient solar collectors, and to test solar water heating systems used in the country.

iv) Another project is the Jordanian solar house which was designed and constructed by the RSS for studying the heating of the house using solar energy and it was found that 30% of the energy required for water and surface heating can be supplied by solar energy.

4.6 Research and Development in the Solar and Wind Technologies in Jordan

Research and development on solar energy applications is being carried out which involves both experimental and theoretical aspects. A theoretical study was carried out by Habali et. al. [12] to investigate space heating by solar energy in Jordan in which five active solar heating systems and two passive systems were used. Their results indicated that 60% of the heating load during the months from January to March may be supplied by the solar energy, whereas the total beating load may be supplied by solar energy in the rest of the year. Furthermore, they found that the passive heating system analysis indicated that 60% of the heating load may be covered by solar energy if a passive solar house is designed. Figure 3 shows the yearly fraction of solar energy in Jordan for the different heating systems which were investigated. The same authors [12] found that using solar energy for space heating and providing domestic hot water system in Jordan is promising and is cost effective.

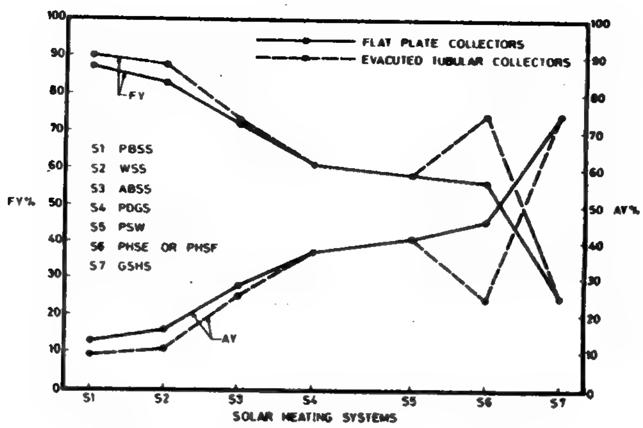

Fig.3. Yearly Fraction of Different Solar Heating Systems in Jordan.

Hamdan and Jubran [13] found that, based on the efficiency per unit cost, the covered plate collector was the most suitable collector for in-store solar dryer, as compared to the bare plate and lined plate collectors.

At present, research is being carried out by the authors on the possibility of using solar ponds in Jordan for generating thermal heat and electricity and the economics of their application. The preliminary results obtained are very promising.

Research on the wind energy application is also being carried out in Jordan. Routine wind data from different stations have been collected and analysed [4]. The monthly average and seasonal wind speeds and the average power density distribution were determined for the different stations [2]. Utilisation of the wind energy for power generation in the most potential wind sites in Jordan was carried out by Habali et al [14] and a cost analysis using the so-called the present value and the unit energy cost method was made for both a single WECS and a wind farm. For both systems, it was found that wind energy conversion system is more economical for generating electricity than the conventional system used by the Jordanian Electricity Authority. For example, the estimated cost of 1kWh is a maximum of 2.2 fils in case of single WECS and 10 fils in case of the wind farm, compared with 27 fils of the cost of 1kWh in case of the conventional used method.

Since Jordan is characterised by low to medium wind speeds the authors are investigating at present, the effect of having an augmenter to increase the initial speed to the wind mill. Figure 4 shows some of the preliminary results obtained by using a delta shape augmenter on the speed. A further research project is also being carri d out to study the effect of the angle of incidence on the ratio of the drag force, D, to the lift force, L, for different geometrical shapes of the turbine blades, aiming to find the most propriate shape which suits a certain wind speed distribut nd power intensify at a site.

Figure 5(a) shows some of the geometrical shapes under investigation and figure 5(b) gives some of the preliminary results obtained. A wind tunnel was also built to test the results.

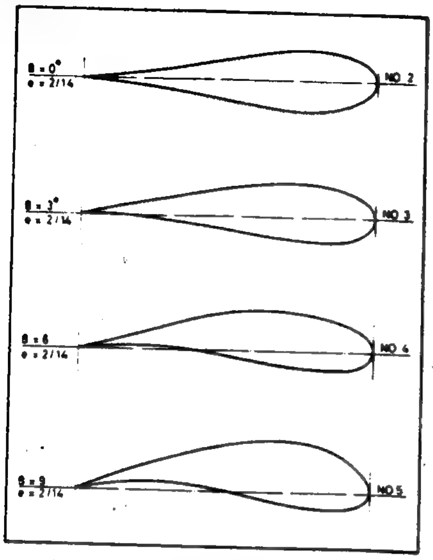

Fig.4(a) Aerofoil Section size 152.4mmx300mm.

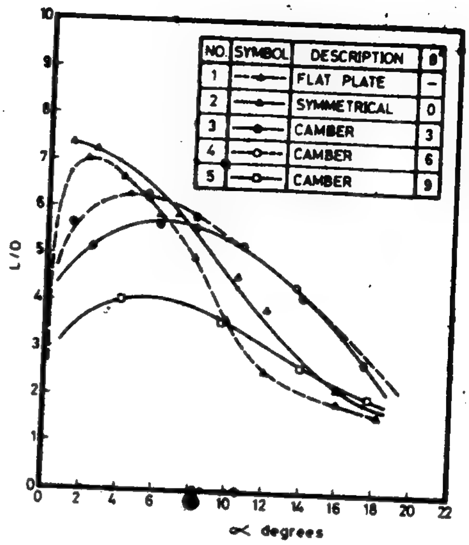

Fig.4(b) Effect of Incident angle on the lift to drag ratio.

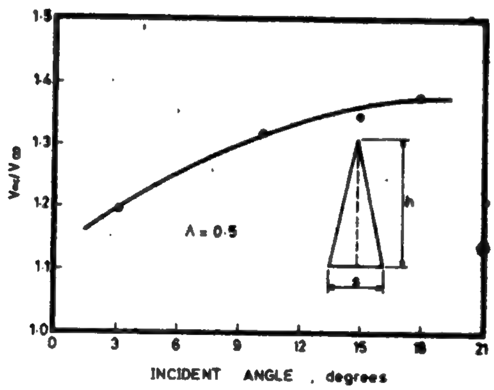

Fig.5 Effect of the Incident Angle on the Augmented Velocity for Aspect Ratio of 0.5.

5. CONCLUSIONS

1. Using solar, wind and solar-wind systems can effectively substitute for a considerable percentage of imported oil especially for meeting the basic energy needs.

2. Among the renewable sources of energy, wind and solar energy resources are the most promising ones in Jordan. The utilisation of such resources is economically, socially and technically advisable, provided that the appropriate technologies and sound applications are selected.

3. Solar, wind and coupled solar/wind systems could have a prominent role in meeting energy demands in Jordan particularly in rural and remote areas. Apart from the stabilization of the population of these areas, these

systems have proved cost-effective.

4. The demand for electrification of the remote and rural areas of Jordan is increasing and all efforts are made to supply villages and settlements with electricity in the near future. Yet a number of these locations may have no chance to be connected to the national grid system due to economical reasons. Hence alternative sources of energy; mainly solar, wind or combined solar/ wind can play a constructive role in this direction.

5. Research and Development in solar and wind energies is in progress at Royal Scientific Society and Jordan University but still much work needs be carried out before these renewable energy resources can make a major contribution.

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3-PHASE SELF EXCITED INDUCTION GENERATOR FOR WIND ENERGY - ANALYTICAL TECHNIQUES AND EXPERIMENTAL RESULTS

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ABSTRACT

If an appropriate 3-phase capacitor bank is connected across the terminals of an externally driven induction machine, an emf tends to be generated. This phenomenon is known as 'Capacitor Self-excitation'. Induced emf and current in the windings will increase up to a level governed by magnetic saturation in the machine. The capacitors provide the magnetising VAR's and, in the event on an external lagging power factor load, also the reactive load requirement. In order to reach a steady state generating mode, some remanent magnetism must be present in the machine core initially.

The induction generator can be employed with the following types of prime movers :

(i) Grid connected induction generator: Mini hydro turbines, wind turbines, gas turbines.

(ii) Autonomous capacitor self-excited induction generator: Micro hydro turbines, wind turbines, diesel/kerosene/biogas engines.

1. INTRODUCTION

While the analysis of grid connected induction generator using the standard equivalent circuit is relatively simple, the self-excited induction generator poses problems due to magnetic nonlinearity. Three methods have been developed to identify the quiescent operating point under saturation for the given speed, load and capacitor. This determines the saturated magnetising reactance and per unit frequency from which the operating air-gap flux is estimated using the magnetisation curve obtained by simulating zero rotor current conditions. The determination of generator response then becomes fairly simple. Using any of these methods families of performance

curves can be obtained and effects of various machine/system parameter can be studied.

To study the design aspects, we require a method by which the generator performance is predicted by using its design data so that the effects of these basic parameters can be assessed. Having identified that for proper prediction of performance, it is essential to estimate correctly the magnetisation characteristics inter-relating air-gap voltage, magnetising current and magnetising reactance under different flux conditions; we must be able to obtain these characteristics from design data to be validated by test results. Thus we will have a design based computation procedure.

Automatic voltage regulator is the major controller to be used with self-excited induction generator, since the frequency variation with load is not significant at constant prime mover speed. Terminal voltage can be maintained constant at different loads by adjusting the capacitive VAR. One method uses switched capacitor scheme, wherein a feed back signal switches appropriate capacitors. This controls the voltage in steps. The second method uses a simulated variable inductor in parallel with a fixed high capacitor, which yields rated voltage at full load at maximum lagging pf. Simulated inductor is a solid state controller, which may be of different types. One scheme is a controlled 6-pulse thyristor rectifier feeding an inductor (on d.c. side) in which the current is varied by controlling the firing angle. In a second scheme the inductor is replaced by a resistor recognising that the controlled rectifier draws lagging VARs at delayed firing angles. But this controller has some losses due to the resistor. A combination of R and L on d.c. side can also be used.

It is important to know how much power a normal induction motor may deliver when used as self-excited induction generator at rated voltage and current. Viability of the induction generator system has to be established considering both technical and economic factors. Typical cost comparison of induction generator with synchronous generator has been made, which suggest that sufficient cost differential exists to augment the cost of capacitor and controller required for self-excited induction generator. This supports the economic advantage of the induction generator over synchronous generator.

2. ANALYTICAL TECHNIQUES

The generating system, Fig.1, consists of an induction machine, driven by a prime mover having 3-phase terminal capacitor to provide self excitation and the load. As the load varies randomly the capacitor has to be varied to obtain desired voltage regulation.

The steady state per phase equivalent circuit of Fig.2 can be used for the analysis, where the symbols used are [1]:

V,I = RMS voltage, current
R,X = Resistance, reactance
F,ν = Per unit frequency, speed

<u>Subscripts</u>
s,r = stator, rotor
l,m,g = leakage, magnetising, air-gap
c,l = capacitor, load

Rotor quantities are referred to stator turns. All reactances correspond to base frequency f. A general partly inductive variable load is considered, connected across the variable capacitor. All the equivalent circuit parameters except the magnetising reactance (X_m) are assumed constant. For a fixed per unit speed of the prime mover, per unit frequency varies with load to alter the negative slip. Core loss is neglected though it can be easily incorporated by including a variable resistance across X_m.

For the given speed, capacitance and load impedance all parameters except X_m and F are known. The first step in the analysis would be to determine these values. Three methods are explained in the following section.

2.1 Methods to Determine X_m and F

Method I - Operational equivalent circuit method :

It has been shown that the positive sequence operational equivalent circuit of the system can be written by simply replacing F by jp in Fig.2, where P is the derivative operator $1/\omega.d/dt$, ω=base radian frequency, t=time and is given in Fig.3. Here i_s is the instantaneous positive sequence stator current related to the winding currents i_{sa}, i_{sb}, i_{sc}.

$$i^{+}_{sa} = \frac{1}{\sqrt{3}}(i_{sa} + a\, i_{sb} + a^2 i_{sc}) \tag{1}$$

where $a = e^{j\frac{2\pi}{3}}$

It will be noted that under steady state, the equivalent admittance seen from the terminals of X_m must be purely imaginary. Expressed in terms of the appropriate circuit parameters, the admittance can be stated as a function of the frequency, F, of the form:

$$Y(F) = G(F) + jB(F) \tag{2}$$

By letting G(F) = 0, F may be determined and subsequent substitution of F in B(F) yields X_m. This approach is conceptually very simple and attractive. However, we have found it relatively demanding computationally.

An alternative approach, producing the same results with somewhat less computing effort is, therefore, proposed and discussed below. It may be regarded as a 'complex frequency' approach to the steady state analysis considered. The operational equivalent circuit, Fig.3, is used but is not seen as a dynamic model capable of representing saturation effects during a transient process in the motor. Referring to Fig.3, the following loop equations can be written:

$$0 = \left[\frac{x_m p\left(x_{1r} p + \frac{R_r}{1-j\nu/p}\right)}{\frac{R_r}{1-j\nu/p} + (x_{1r} + x_m)p} + (R_s + x_{1s}\, p) + \frac{(R_L + x_L p)x_C/p}{R_L + x_L p + x_C/p} \right] i^{+}_{s} \tag{3}$$

The corresponding characteristic polynomial is

$$k_1p^4 + k_2p^3 + k_2p^2 + k_3p + k_5 = 0 \tag{4}$$

where $k_1,\ldots,k_5$ are constants depending on machine parameters, capacitance, speed, and load impedance.

If the load is purely resistive, eqn.4 simplifies to a polynomial of third order, ($k_1 = 0$).

Self-excitation would occur if any one of the roots of the polynomial of eqn. 4 has positive real part. For a given per unit speed ν and load impedance Z_L, there is a minimum or critical value of C that will make the real part of one of the roots positive. Self-excitation is sustained at that speed for values of C higher than this minimum. In fact the critical value of C just makes the real part of the root zero.

Now consider the constant speed situation in which a capacitance higher than the critical value is connected. The real part of one of the roots of eqn.4 will be greater than zero. The other two roots will have large negative real parts signifying current components that die down rapidly. These two roots lie in the second and third quadrants. Due to self-excitation, the terminal voltage V_T and the air-gap voltage V_g continue to increase. Eventually, the principal magnetic flux path in the machine saturates, and effective magnetising reactance X_m decreases. As X_m decreases, the magnitude of the real part of the root (which is positive) will also decrease and will ultimately reach zero for a particular value of X_m. The stator voltage continues to rise as long as the real part of this root is positive. Voltage rise ceases as the real part becomes zero, and the generator is in the steady state operating condition.

The physical process by which steady state is reached by way of magnetic saturation suggests a computation procedure which avoids transient response analysis. This procedure consists of the following steps:

(i) Determine the roots of the polynomial, eqn.4, for the given machine parameters, X_C, speed, and load impedance. Initially X_m is taken to correspond to unsaturated conditions.

(ii) Re-calculate the roots for values of X_m decreasing in suitable steps from the unsaturated (measured) values (the real part of one particular root is positive).

(iii) Identify the value of X_m that makes the real part of the particular root zero.

(iv) Use the value of the particular root on the imaginary axis to determine output frequency under steady state.

It will be noted that $F<\nu$, i.e. the per unit slip $s=F-\nu$ is always negative as it should be for generator operation.

Having determined F and X_m under steady state, the next step is to calculate the air-gap voltage V and terminal voltage V_g. For this purpose one can use information regarding variation of X_m with V_g/F, which relates to the air-gap flux. The information required can be obtained experimentally by driving the induction machine at synchronous speed corresponding to the line frequency, i.e. F=1, and measuring the magnetising reactance for different input voltages at line frequency. A curve of V_g/F vs. X_m can be

plotted using the experimental results. From this curve, V_g/F for the above steady state X_m can be obtained. Knowing F, the air-gap voltage V_g can be computed.

With V_g, X_m, F, X_C, ν, R_L, X_L and machine parameters known, calculation of the terminal voltage V and the load current is straight forward using the steady state equivalent circuit of Fig.2. The rotor current I , stator current I , input torque, efficiency, etc. can also be calculated using Fig.2. Expressions for the respective variables are summarised as follows [2].

$$I_s = \frac{V_g/F}{\dfrac{R_s}{F} + jX_{1s} - \dfrac{X_C(X_L F + jR_L)}{F^2 R_L + jF(F^2 X_L - X_C)}} \tag{5}$$

$$I_r = \frac{-V_g/F}{\dfrac{R_r}{F - \nu} + jX_{1r}} \tag{6}$$

$$I_L = \frac{-jX_C I_s}{FR_L + j(F^2 X_L - X_C)} \tag{7}$$

$$V_t = (R_L + jFX_L)I_L \tag{8}$$

$$\text{Input power,} \quad P_{in} = \frac{-3|I_r|^2 R_r}{F - \nu} \tag{9}$$

$$\text{Input torque,} \quad T = \frac{P_{in}}{\omega_s} \tag{10}$$

(ω_s = syn. speed in mech. rad./sec.)

$$\text{Output power,} \quad P_{out} = 3|I^2|\ R_L \tag{11}$$

The flow-chart of the computer programme is given in Fig.4.

2.2 Computer Algorithm

In order to develop a computer algorithm to determine the steady state performance using the techniques prescribed, it is desirable to have a program or subroutine to calculate the roots of a polynomial with complex coefficients, and also to fit a curve showing the variation of X_m with the [illegible] flux (proportional to V_g/F). This curve has to be fitted using the observations from the 'synchronous speed' test.

This section presents a general computer programme which calculates the steady state output voltage, frequency, power, efficiency, etc. of the unit for given values of speed, terminal capacitance and load impedance. The program maybe used to determine the steady state operating characteristics

of the self-excited induction generator. For example, as a particular case it may be of interest to examine the variation output voltage and frequency with load impedance for a given C and ν in order to assess voltage and frequency regulation. The general program can be used for this purpose by just varying the load resistance over a specified range and listing the output voltage and frequency for each load impedance.

After reading the machine parameters, C, ν, R_L and X_L, the programme start by choosing the unsaturated value of X_m. After computing the coefficients for eqn.4, the roots of the polynomial of that equation are determined. If C has been chosen above a critical or minimal value to cause self-excitation, one of the roots of the polynomial will have a positive real part. X_m is then reduced in steps and the roots of the polynomial recalculated until the positive real part changes sign. By interpolation, X_m to yield zero real part of that root is determined. The imaginary part of the root is F.

Based on the stored data regarding the variation of V_g/F with X_m, the particular value of V_g/f corresponding to the given X_m is computed. Using eqn.4, output voltage, current, power, etc. are calculated and stored.

2.3 Characteristics

Now all the parameters of the equivalent circuit, Fig.2 are known. To determine the system response, we must determine the air-gap flux proportional to normalised air-gap voltage V_g/F corresponding to the saturated X_m. already obtained. We need the magnetisation characteristics V_g/F versus I_m from which V_g/F versus X_m can be evolved. These characteristics are obtained experimentally by 'synchronous speed test'.

Knowing V_g/F and the parameters, generator response can be obtained using the circuit of Fig.2 as already reported. The relevant equations can be simulated on the computer to print out the response quantities.

The performance characteristics of interest are:

(i) Variation of response quantities, especially V_L with power output at constant C and V.

(ii) Variation of C or capacitive VAR with power output to maintain V_L constant.

Both these characteristics can be obtained by an iteration process in the computer program. To obtain characteristic

(i) R_L, and X_L are varied in steps keeping C and ν constant. To obtain characteristics

(ii) for each load impedance C is varied to obtain required V_L, and the process repeated for different load impedance.

3. LOAD TEST ON 3-PHASE SELF EXCITED INDUCTION GENERATOR

The test is performed on the 3-phase self excited induction generator and its load characteristic is drawn for a 7.5 Kw machine.

Induction Generator Specification

Delta connected, 50 Hz, 415 volts, 7.5 Kw, 1450 rpm, 14.0 amps.

D.C. Motor Specifications

Compound winding, 11 Kw, 1500 rpm, 220 volts, 57 amps.

Induction Generator Fan Specifications

Star connected, 0.18 Kw, 415 volts, 2750 rpm, 0.7 amps.
This motor is provided to cool our 7.5 Kw induction generator.

The circuit diagram for load test on 3-phase self excited induction generation is shown in Fig.5. D.C. motor acts as the prime mover for the induction generator. We can draw the load characteristics of the induction generator by reading obtained from the load test given in Table 1. These results were obtained when the motor was running at synchronous speed and the voltage kept at a constant range of approximately 415 volts throughout the experiment. In order to achieve self excitation two capacitor banks of 10 KVAR each were connected parallel to each other.

4. CONCLUSIONS

The present study has confirmed the widely published fact that a normally designed 3-phase induction motor can be used as a self excited three phase induction generator for supplying three phase resistive load and inductive load. It has been shown that in the low power range, the induction machine becomes an alternative to the normally used synchronous generator. The test results have shown that a 3-phase 7.5 Kw induction motor needs a three phase bank of 20 KVAR to ensure the phenomenon of self excitation in the machine, and the combination can successfully supply a load of 6.8 Kw as a self excited induction generator. In a practical situation the inducation generator will be driven by a wind turbine.

5. REFERENCES

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Table 1 : Load Test on a 3-Phase Self Excited Induction Generator (Two 10 KVAR Banks of Capacitor Connected in Parallel) (P.F. = 1), AC Voltage Line to Line, V_{LL}=415 Volts, Speed, N=1500 RPM

Serial Number	A.C. Power Output, Watt (W)	A.C. Load current, A (I_L)	A.C. Capacitor current, A (I_C)	A.C. Machine current, A (I_m)	D.C. Input: Field current, A (I_F)	D.C. Input: Current, A (I_{DC})	D.C. Input: Voltage, V (V_{DC})	Speed (RPM) (N)	Power output, watt (W)
1.	0	0(no load)	6.25	6.1	2.4	4.2	250	1500	0
2.	1725	2.4	6.6	6.7	2.35	9.6	250	1500	1725
3.	2515	3.5	7.0	7.0	2.35	12.0	250	1500	2515
4.	3090	4.3	7.2	7.2	2.30	14.0	250	1500	3090
5.	3674	5.1	7.6	7.75	2.30	18.0	250	1500	3674
6.	3746	6.2	8.1	8.5	2.28	23.0	250	1500	3746
7.	3818	5.3	8.5	9.5	2.25	26.2	250	1500	3818
8.	4107	5.7	9.0	10.5	2.85	30.0	250	1500	4107
9.	5548	7.7	10.0	12.3	2.1	34.0	250	1500	5548
10.	6628	9.2(full load)	14.3	2.15	37.0	250	1500	6628	6628

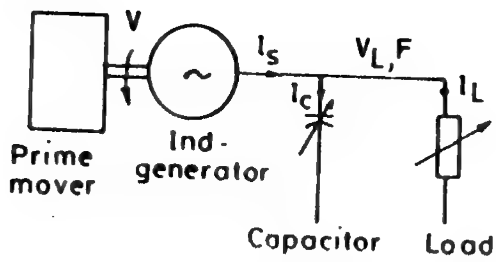

Fig. 1 Self excited induction generator system

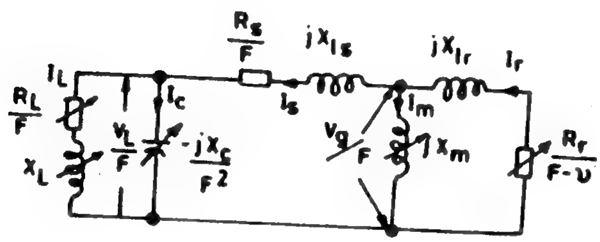

Fig. 2 Steady state equivalent circuit

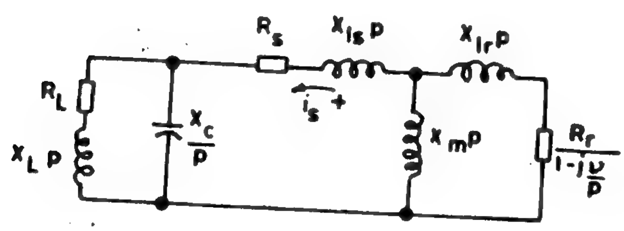

Fig. 3 Operational equivalent circuit

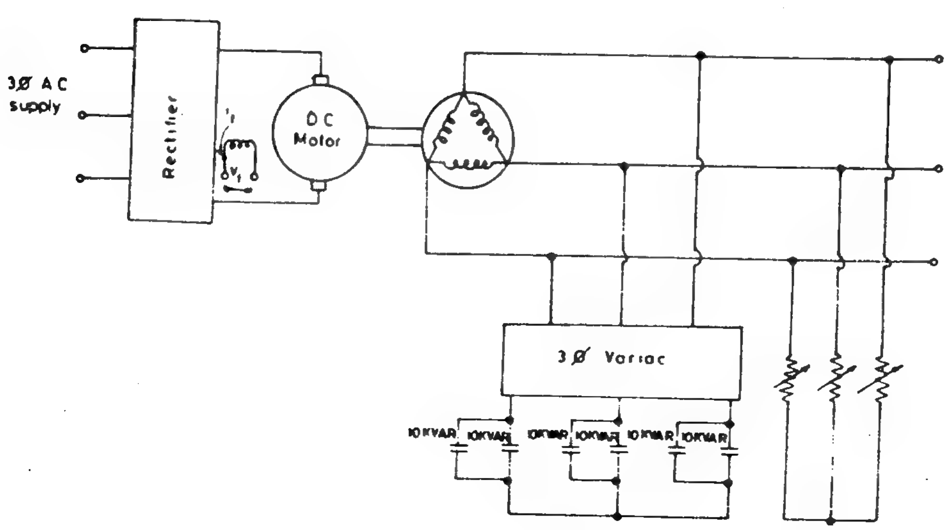

Fig 5 Circuit diagram of load test on three phase self excited induction generator

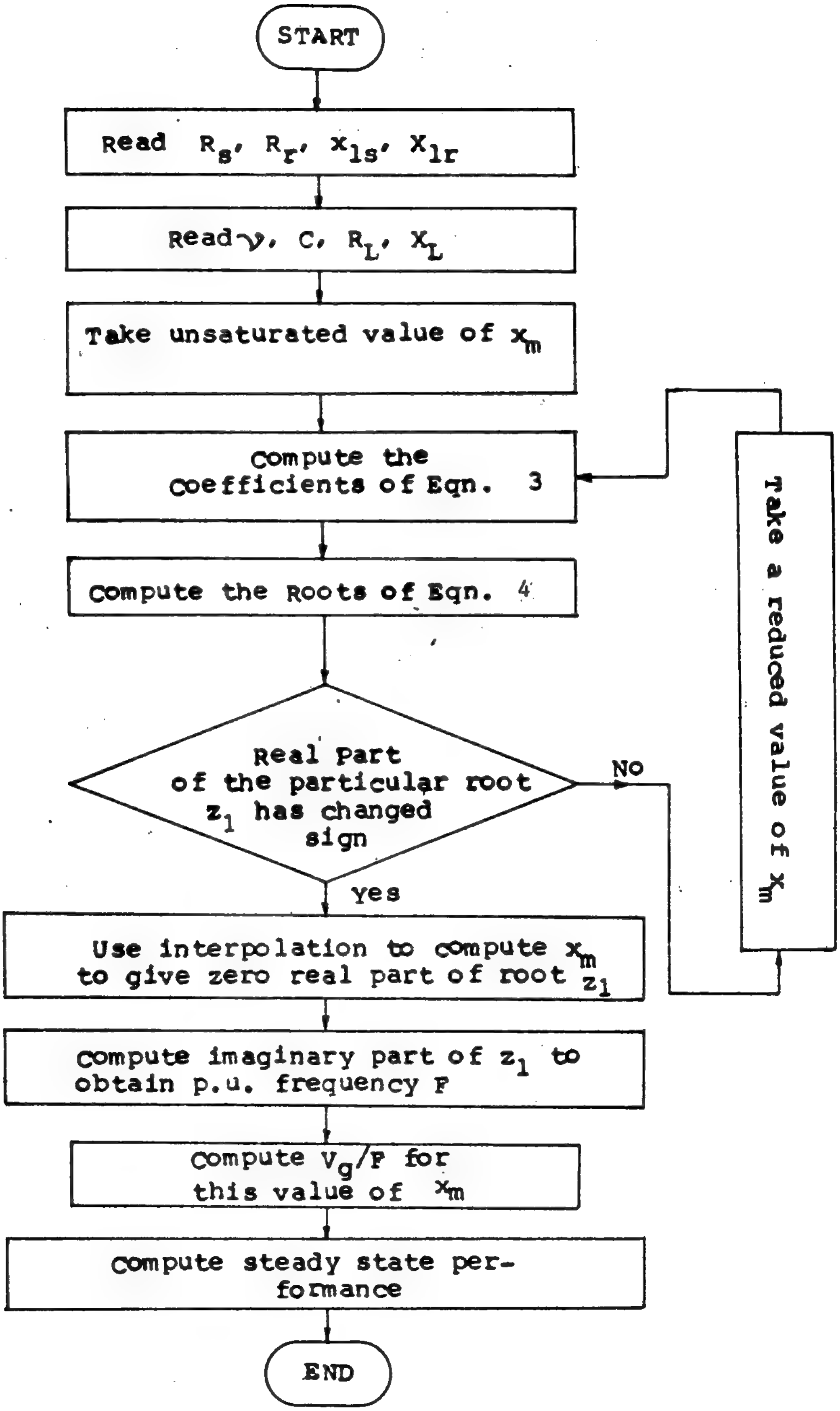

FIG. 4 Flow Chart of the Computer Program to Determine Steady State Performance

SECTION XIX

ENERGY POLICY AND PLANNING

ENERGY WITHOUT POLLUTION: SOLAR - WIND - HYDROGEN SYSTEMS: SOME CONSEQUENCES ON URBAN AND REGIONAL STRUCTURE AND PLANNING:

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ABSTRACT

Prices of Solar- Wind- Hydrogen- Systems are compared to other kinds of power plants. Energy supply without pollution could be started immediateley. Research and product management are to be concentrated on combined systems as Solar-Wind-Hydrogen power plants permitting the exploitation of solar energy also during the night hours. Real estate, land use planning as well as townscape and regional structures will be changing in a certain manner.

1.) INTRODUCTION

World wide overproduction of military goods as well as pollution ask for drastic reduction and liquidation. Production and storage of energy on the base of fossil fuels and nuclear power are significant sources of harmful substances and doomsday- weapons. The burden capacities on mankind and nature are sufficient only for a verry small transitional period. Then energy is to be generated and stored without pollution and doomsday perspectives.

2. SOLAR WIND HYDROGEN SYSTEMS

Solar energy in form of direct radiation or wind is disposable everywhere but not permanent. In the center of research for operating technologies we actually find the storage problem. Starting by thought and research of

Justi (1960), Bockris and Justi (1980) Nitsch and Winter (1986) and in counterpart to Schaefer (1987) the regenerative energy potential in the Federal Republic of Germany is taking considerable dimensions when storing non used energy in order to use it in case of demand. The technology concerned is the electrolysis of water by electric current generated with solar or wind energy. The resulting storage medium is Hydrogen. This gaz delivers only water as "garbage" when being burnt in Otto engins or turbines.

3. COMPARISON OF PRICES

Today`s limits for prices of electric power produced by Wind energy converters are moving between 5.9 to 8 Pfennig per kwh. (Lindley 1987). When generating for example 7 000 kwh of electric power by different kinds of power plants investments and prices are given in table 1.).

TABLE 1

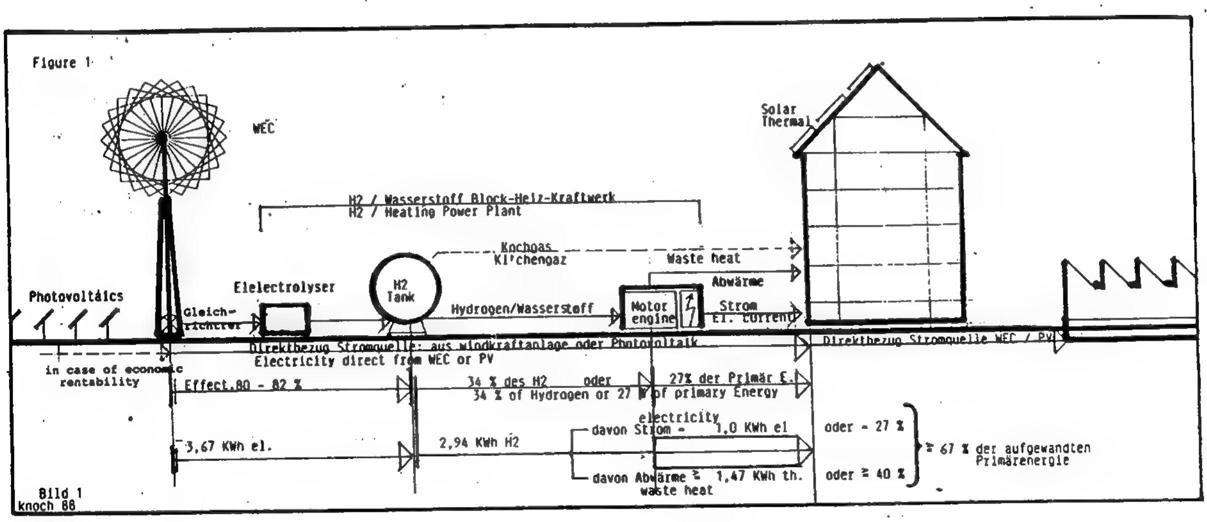
1	2		3	4		5	6
Kind of Power Plant	DM per KW inst corresponding to travel time of plant	tr. time	kWh/a generated	Investion per KW inst. (X- times of carbon pp)	DM/KW inst.	Pfg./kWh inclusive fuel costs	Remarks
Nuclear Power Plant 1300 MW Travel Time	5.000.-	7000 h	7 000	2,0	5.000.-	14.9	without waste heat used
WEC-H2 Power Plant 55 KW Travel Time	4.100.-	4250 h	7.000	1,6	2.600.-	25.0 11.0	without waste heat used with waste heat
WEC travel time	3.880.-	2600 h	7.000	1.5	1.140.-	5.9	storage problems
Carbon power plant travel time	2.500.-	7000 h	7.000	1,0	2.500.-	17.3 11.3	without waste heat with waste heat
PV-Solar Europe travel time	65.000.-	1600 h	7,000	26,0	15.000.- 30.000.-	103.0 206.0	Storage problems
PV-Solar Sahara 2 000 travel time	2.56o.-	3600 h	7.000	1,0	1.320	4.0	storage problems
WEC 2 000		2600 h	7.000		500.-	2.0	

Explanations:
pa : per annum
kWh/a Kilowatt hours per annum
kw inst. : Kilowatt installed
WEC : Wind Energy Converter
WEC-H2-PP : Windenergyconverter- Hydrogene- Power plant
PV- Solar- P : Photovoltaic - Solar- Power Plant
Sahara 2000 : Implementation Sahara in the year 2 000
WEC 2 000: Under conditions of mass series production / above 10 000 units pa.
(All other indications 1987)

Base of calculations:
1 $ = 1,80 DM
Annuities 11%
no tax reduction

Following Tegström (1986) electric power resulting from WEC is partly taken to produce hydrogen. The advantage in comparison to Photovoltaic cells is that wind-energy can be used too during the night hours if wind is blowing. By this way an energy base is given which allows to renounce to global geopolitical strategies (DFVLR 1987) when using solar energy.

The effectiveness of market sold electrolysis plants are about 80 %. When burning hydrogen the maximum effectiveness is 34 % . Waste heat using is possible. Thus the wind - hydro heat- powerplant is turning out to be the cheapest energy supply system in the regions of middle and northern Europe. Other Regions with wind speeds of 6 meters per second on average of the year like Tripolis may be verry adapted to start projects of wind Hydrogene power plants. Though there is no chance of using waste heat because of the climate prices may move about 15 Pfennig per kwh or below (see point 5.3). The energetic effectiveness of the Wind Hydro Power Plant will be about ?7 % . When using waste heat effectiveness is amounting to 65 % and more (Fig. 1).



4.) POTENTIALS OF WIND

Using national coastal regions for the implemen-tation of Wind energy converters in a large scale, the existing gaz pipeline network can be utilized to distribute the hydrogene obtained on the base of windenergy generated electric power. For the beginning some isle-nets could be constructed. At the same time they are the experimental projects to verify the whole system.

Coast lengths in the EC along North Sea and Atlantic are about 4 700 km. Locations with wind speeds of 6-7 meters per second at the average of the year may be found at rather

every place along the european coastal regions mentioned above (Müller 1987). To be utilized for the implementation of WEC 25 % of surfaces might be used on 40 km depth, what means 47 000 resulting square kilometers. Installing 2 WEC per hectar, 9,4 Millions of WEC at 65 kw would be a gigantic number of unities, but a good number for mass series production. The resultimg capacity of 611 Gigawatt would generate far enough energy to substitute today's exploitation of oil, coal and uranium for electric power generation within the EC region along North Sea and Atlantic.

5.) CONSEQUENCES ON REGIONAL PLANNING AN URBANISM

Space intensive energy generation demands regulated land use planning as concerne the implementation of WEC-fields instead of nuclear or fuel power plants. Regarding the actual legislative basis of town and country planning there are some doubts about the ability to new energy politics, wind energy converting or solar farming both demanding big surfaces of landscape and soil. On The other hand there are even today prices of 7 to 11 Pfennig per kwh spent into the public network by private producers. So there are economically interesting conditions for wind farming. (Table 2)

table 2

Table 2

WINDFARMING

Revenues per ha (10 000 square meters) and year.

surface, occupied by WEC / kw inst.	8 Pfg/KWh	11 Pfg./ KWh	14. Pfg. / KWh
50 m2 /KW inst.	11 340.- DM	27 000.- DM	43 710.- DM
100 m2 /KW inst.	5 670.-	13 500.-	21 855.-
150 m2 /KW inst.	3 780.-	9 000.-	14 580.-
200 m2 /KW inst.	2 835.-	6 750.-	10 935.-

Notes:
Base of calculations:

- 5,9 Pfg. / KWh electric Power when leaving the plant;
- 800 $ per KW installed (Lindley 1986)
- 2 700 hours running time per annum;
- 11 % annuity
- without tax reduction

knoch 1988.

5.1) Generating hydrogen in central plants located within territories rich of wind or / and sun like deserts (Sahara) is possible. This kind of production offers the possibility to use transportation and pipeline structures to export hydrogene analogous to the distribution of gas. (Winter , Nitsch 1986, DFVLR 1986) Disatvantages are their crisis-vulnerability in case of territorial conflicts and

geostrategic politics like in the Middle East. Nevertheless in case of peace there are possiblities for economic and technological evolution as condition for independent regional development and growth.

Fig, 2

Coast zones with wind speeds of 5 - 6 m /sec and more on average of the year overlaid with gaz pipelines infrastructure. (Ref: Winter and Nitsch (1986) and author`s addition.)

5.2.) Electric power and hydrogen generation systems on the basis of WEC combined with decentralized isle-Nets could be immediately set up. This offers the opportunity of exploiting solar energy by matter of windcraft during the hours without daylight, excluded when working with photovoltaics. Independance of exterritorial crisises and fossil fuels would be guaranted. Possibilities to connect local or regional gaz distribution are important.

5.3 The roof-scape of urban or rural agglomerations may be constructed with solar / PV pannels and intermediated hydrogen generation. The price level actually given is too high, even when producing the PV panels in modern factories working in three shifts as proposed by some pioneers (Strese 1988). Proceeding in the same manner when dealing with mass series production of WEC one would arrive at comparible prices of 2 Pfennig per kwh.. Regarding to the number of WEC necessary to substitute traditional electric power plants in the year 2 000 this price proportion might be a realistic consideration. Coast regions in Europe as well as the roofscape of urban areas by this way might have an

interesting future as concernes 'architecture, town- and landscape.

5.4) The changing system of private isle nets and public utilities is to be organised by state planning nation wide, within the EC and in cooperation with other countries.

5.5) Energy supply for industrial plants and factories might be assured by hydrogene power plants. The relative high price-level is paralised when providing the plants directly by wind generated electric power. As pointed out above the price per KWh could move just down to about 2 Pfennig. When running the system at 5o per cent in combination with Hydro-Power the price will move up to 13.5 Pfennig per KWh . That is 1 Pfennig below the nuclear power plant`s electricity. All this still without exploiting waste heat.

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ON THE PLANNING FOR UTILIZATION OF SOLAR ENERGY IN THE ARAB COUNTRIES

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ABSTRACT

Solar energy is a long lasting and renewable natural energy resource available all over the world and especially in the Arab countries where it has the best conditions for utilizations. The planning to utilize solar energy on the local and regional level is of great importance. Therefore a unified effort towards this planning and its implementation is essential. Present state of solar energy usage is considered and also the future state of its utilization. Influencing factors drive utilization state to aimed objective are described and their individual planning processes are carried out. The overall plan of energy utilization taking into consideration the interaction between the influencing factors and the present utilization state is developed.

I. INTRODUCTION

The location of the Arab countries near the equator, and their vast areas that fall within the greatest deserts in the world, enable them not only to utilize solar energy but also to possibly export it. As of now no major plans are being considered to achieve these goals while complete reliance on conventional sources is evident in all of them especially the oil producing.

The planning to utilize solar energy on the local and regional levels is of great importance. For the limited and scattered efforts ought to be unified, directed, and organized on local and regional levels. To do so it is essential to study the present state of solar energy utilization, and determine the factors that initiate the transformation to the desired state of maximum reliance on solar energy. The interaction between the utilization state at any point in time, and these factors will yield the expected trend towards the goal.

To overcome limitations and differences the planning processes are made general and flexible, and can be applied on a local or a regional level. These planning processes are viewed as input output system with the present state of utilization as input, and the required future state as output. The influencing factors can be viewed as driving force for the transformation

process. (Fig. 1) shows an overview of this planning process.

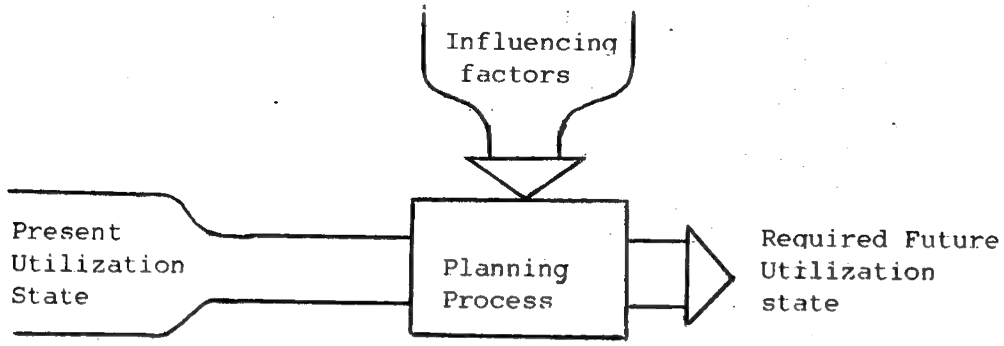

Fig. 1 : Overview of the planning process

II. PRESENT STATE

In this section the present state of solar energy utilization is considered. The elements of this state generally describe present status of solar energy existence, its usage and problems, or ways of this usage. The elements accordingly are:

a - Average radiation intensity of solar energy in the Arab countries is high.
b - Average daily sunshine duration throughout the year in the Arab countries is above average.
c - Lack of utilization of solar energy either on the local or the regional level.
d - Major reliance on conventional sources of energy by all the Arab countries.
e - Lack of implementation plans on the local level, though there is a desire for utilization.
f - No unified strategy on the regional level except scattered efforts by some countries.

III. REQUIRED FUTURE STATE

According to the above state of utilization, the objective is to increase such utilization, and to reach the goal through the interaction with some influencing factors. The elements of this new state generally describe the status of the present state elements after sufficient time span for the planning processes, that will follow, to take place. The elements are listed as:

a - Towards the maximum utilization of solar energy by the Arab countries.
b - Less reliance on conventional sources by most or even all of the Arab countries.
c - Design and implementation plans on the local levels.
d - Established unified strategy on the regional level.

In addition, future state will bring up other elements such as:

a - Mastering solar technology
b - Raise standard of living
c - Increase research activities
d - Improve the efficiency of solar technology.

IV. INFLUENCING FACTORS

a) Description:

The objective to reach the future state of solar energy utilization depends on some factors. These factors defined below are called the influencing factors. The influencing factors present status and their most suitable position will be treated later. These factors are found not only to require individual planning processes but also to interact with each other. Later in the paper a clarification on how they are correlated is discussed. The factors considered here are listed according to their relative importance:

1. Research and development
2. State of technology
3. Technical skills development
4. Investment

In addition, a mointoring factor is added here that reflects growth of demand of energy usage as one side, and decay rate of current conventional energy sources as another.

b) Status:

Scanning the present state of the influencing factors within the Arab countries, the following conclusion can be derived. Research and development is limited and scattered with no unified objective. The state of technology mainly is not considered, and is neglected in many cases. The technical skills are limited and no specific educational or training programs are adopted. Most Arab countries allocate a limited investment for solar energy research activities and utilizations. The important factor of the increasing demand on energy and the decay of the conventional energy is mostly not considered, especially by the oil producing countries.

The planning processes, to be introduced later, is aimed at changing and increasing the levels of the present status of the influencing factors in such a way to ensure proper transformation of the present utilization state to the required future state. Table (1) shows the present state and the necessary status of the influencing factors.

Table 1 : Present and necessary status of the influencing factors

How related to? / Factor	Present Status	Necessary Status
R & D	Limited	Intensive
State of Technology	Not considered	Strongly considered
Technical skills	Limited	Available
Degree of relative investment	Limited	Proper
Demand & Decay	Not considered	Highly considered (indicator)

V. RELATIONSHIP BETWEEN INFLUENCING FACTORS AND ENERGY UTILIZATION STATE

The first two elements of solar energy present state of utilization presented earlier are not affected by the influencing factors. The next two elements can be combined in one category called here degree of usage, and the last two elements are related to application of solar energy either locally or regionally to be called here application plans. The relationship between each of these two categories and the influencing factors is estimated using 4 level scale. These levels are strong relation, medium relation, partial relation, and no relation. These relationships are shown in Table (2).

Table 2 : Influencing factors-utilization state relationship.

Energy utilization state / Influencing factors	Degree of Usage	Application Plans
Research and development	Partial relation	Strong relation
State of Technology	Strong relation	Medium relation
Technical Skills development	Medium relation	Partial relation
Investment	Strong relation	Strong relation
Demand or energy versus decay of convertional energy	Medium relation	Strong relation

VI. OVERALL PLAN

The overall planning processes are viewed as a means of establishing a driving force necessary to transfer the present state of solar energy utilization to the required future state. This driving force is the necessary levels of the influencing factors which are described before. The planning processes take into considerations the interaction between the present utilization state and the necessary levels of the influencing factors in one hand, and the interaction between the influencing factors on the other. The planning steps easy to follow, flexible, and general to implement on the local or regional level. Fig. 2 shows a general block diagram representation of the planning process. The present levels of the influencing factors and the required planning process for each of them is indicated. The necessary levels of these influencing factors are accumulated and imposed on the process.

The planning steps for each influencing factor are given together with their corresponding flow chart representation.

a) Planning for Research and Development:

The proposed planning steps for research and development are:

1 - Establish research body and facilities
2 - Survey of previous research work in the field
3 - Collect data on possible applications of solar energy
4 - Identify research problems according to applications
5 - Classify research problems according to types, urgency and places of applications.
6 - Set implementation time schedule
7 - Allocate appropriate funding

8 - Execute the research programmes
9 - Evaluate research results and decide on direct field applications projects or pilot projects.

The flow chart representation of these planning steps is given in Fig. 3.

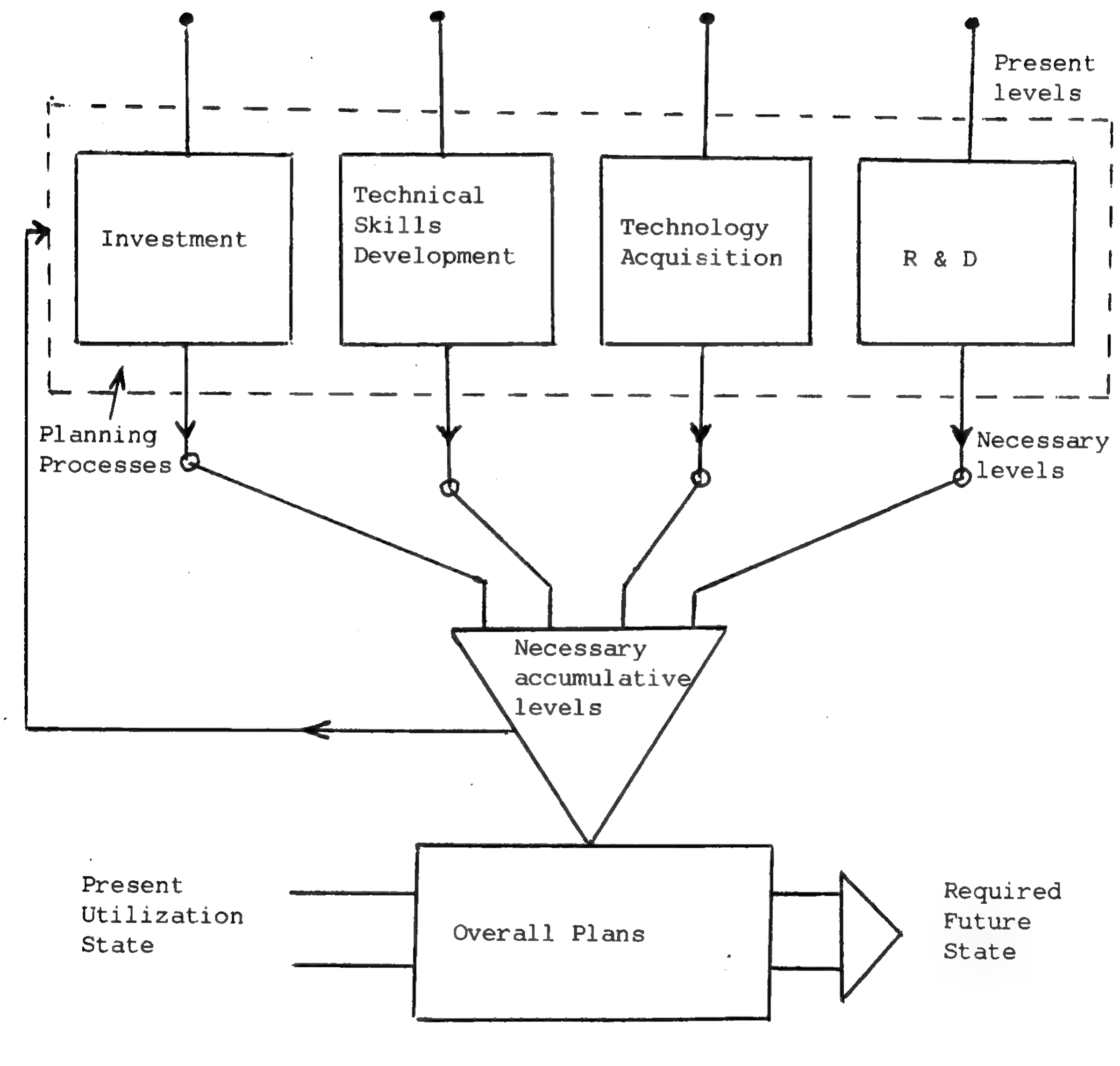

Fig. 2 : Overall Planning Processes.

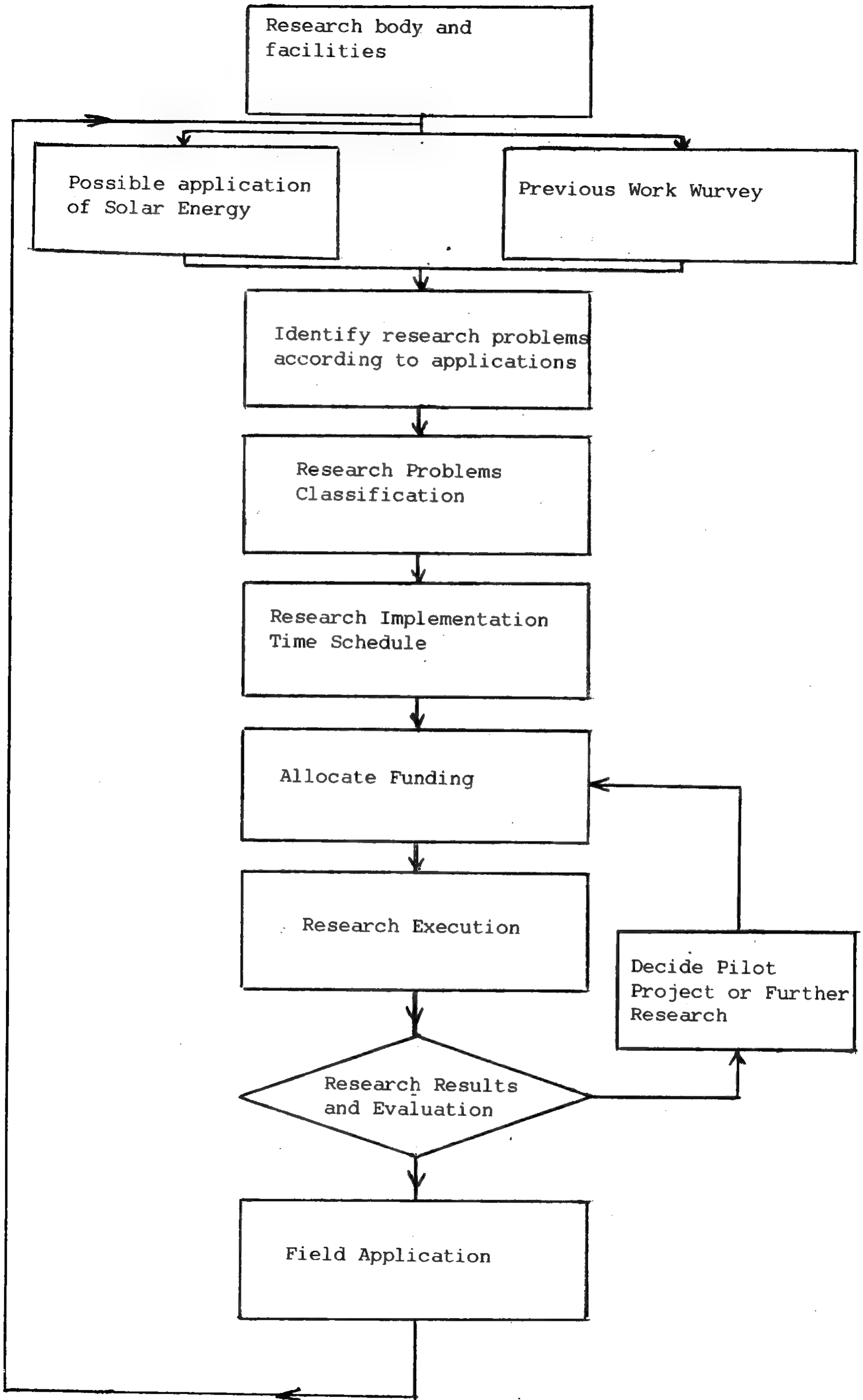

Fig. 3 : Planning steps for R&D on local and regional level.

b) Planning for technology acquisition:

The proposed planning steps are:

1 - Survey of the existing technologies
2 - Identify needs and applications
3 - Evaluate the technologies according to their capabilities and requirements and select the most appropriate, and set its specification.
4 - Decidé on either to manufacture or to import
5 - In case of importing (purchasing) the following steps are required:

a) Call for tenders
b) evaluate the tenders according to the adopted specifications and evaluation parameters, and select the most appropriate.
c) Contracting
d) installation, follow up, testing and operation
e) check performance versus objective.

6 - In case of manufacturing the following steps are required:

a) Specify manufacturing requirements
b) call for tenders
c) select appropriate tender to meet the objective
d) contracting
e) execution of the contract
f) production

Flow chart of the planning steps is shown in Fig. 4.

c) Planning for Technical Skill Development:

The proposed planning steps for technical skills development are:

1 - Survey of the required qualifications.
2 - Survey of the existing educational institutions (on the local and the regional levels) and their capability of satisfying such qualifications.
3 - In case of the lack of satisfying the qualification then:
a) introduce necessary changes or
b) allow for abroad training

4 - In case of satisfying qualification, set up the required training program to accomodate the trainees.
5 - Test the capabilities and knowledge of the trainees against technology and R & D requirements.
6 - In case of discrepancy introduce necessary modifications.

Flow chart representation of these planning steps is given in Fig. 5.

d) Planning for Investment:

The proposed planning steps are:

1 - Estimation of the required investment
2 - Motivate the public using the available news media by compaigning on the potentiality and importance of solar energy to encourage the investment on solar energy.
3 - Search for sources of financing locally or regionally including joint venture.

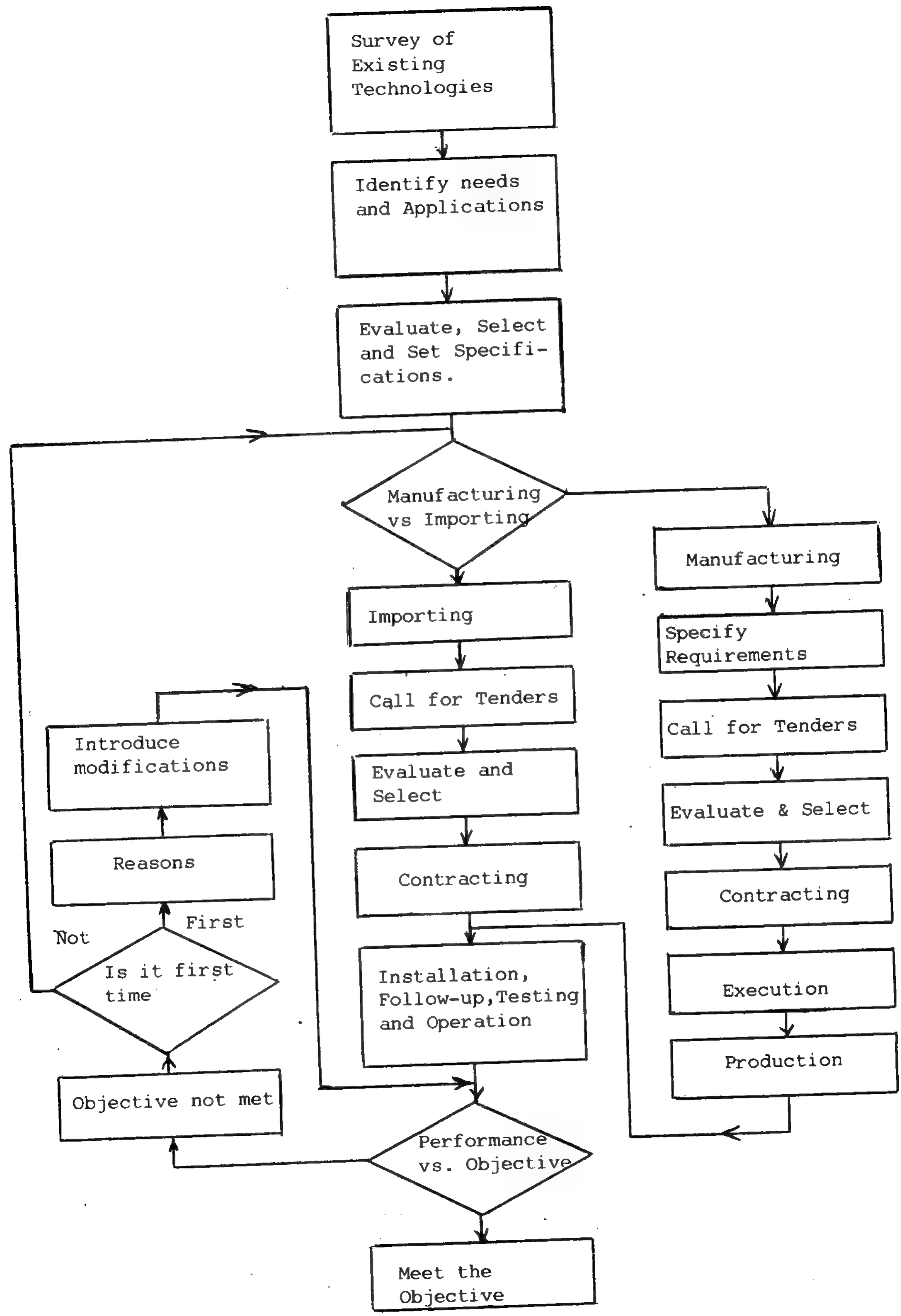

Fig. 4 : Planning Steps for Technology Acquisition.

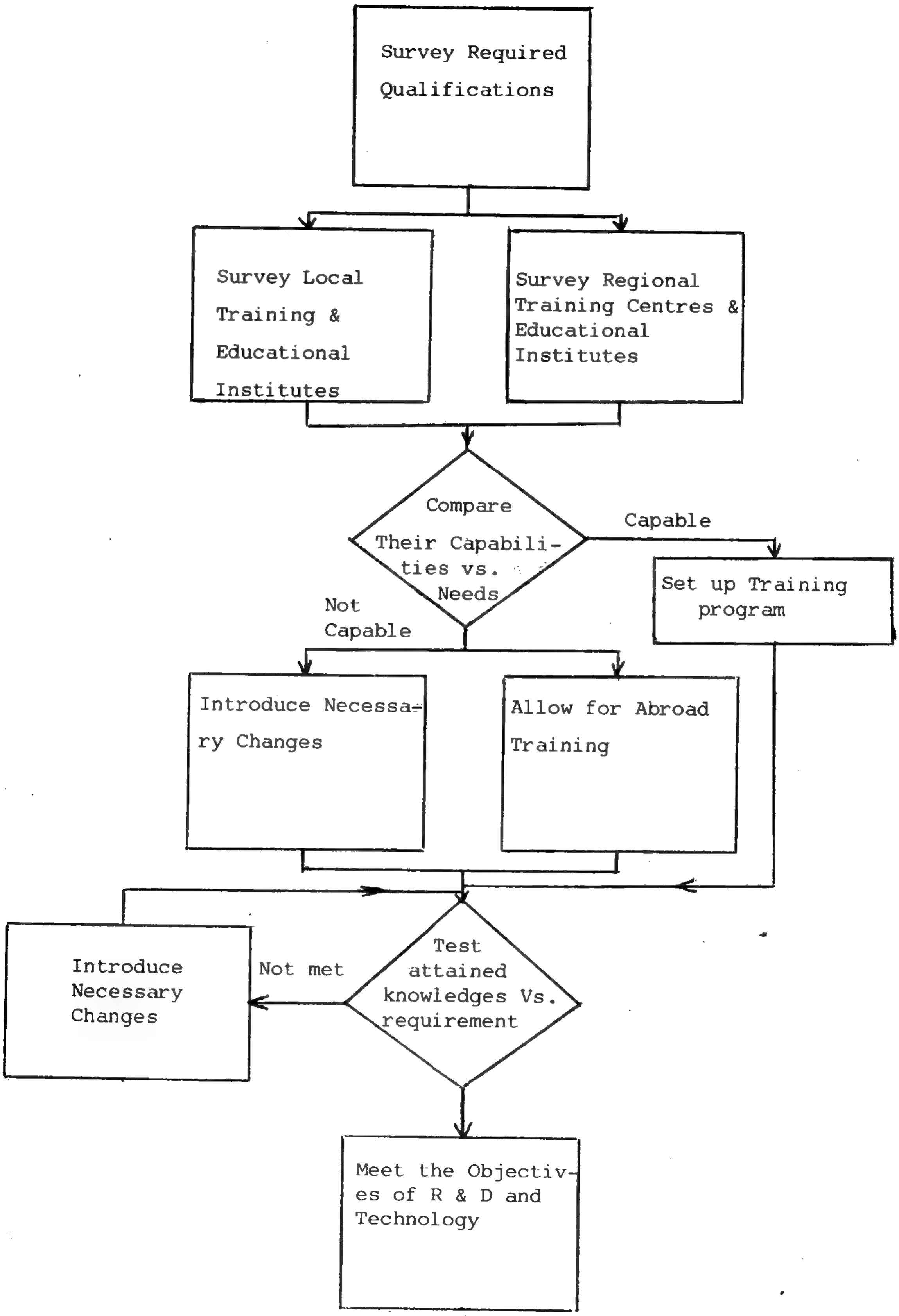

Fig. 5 : Planning Steps for Technical Skill Development

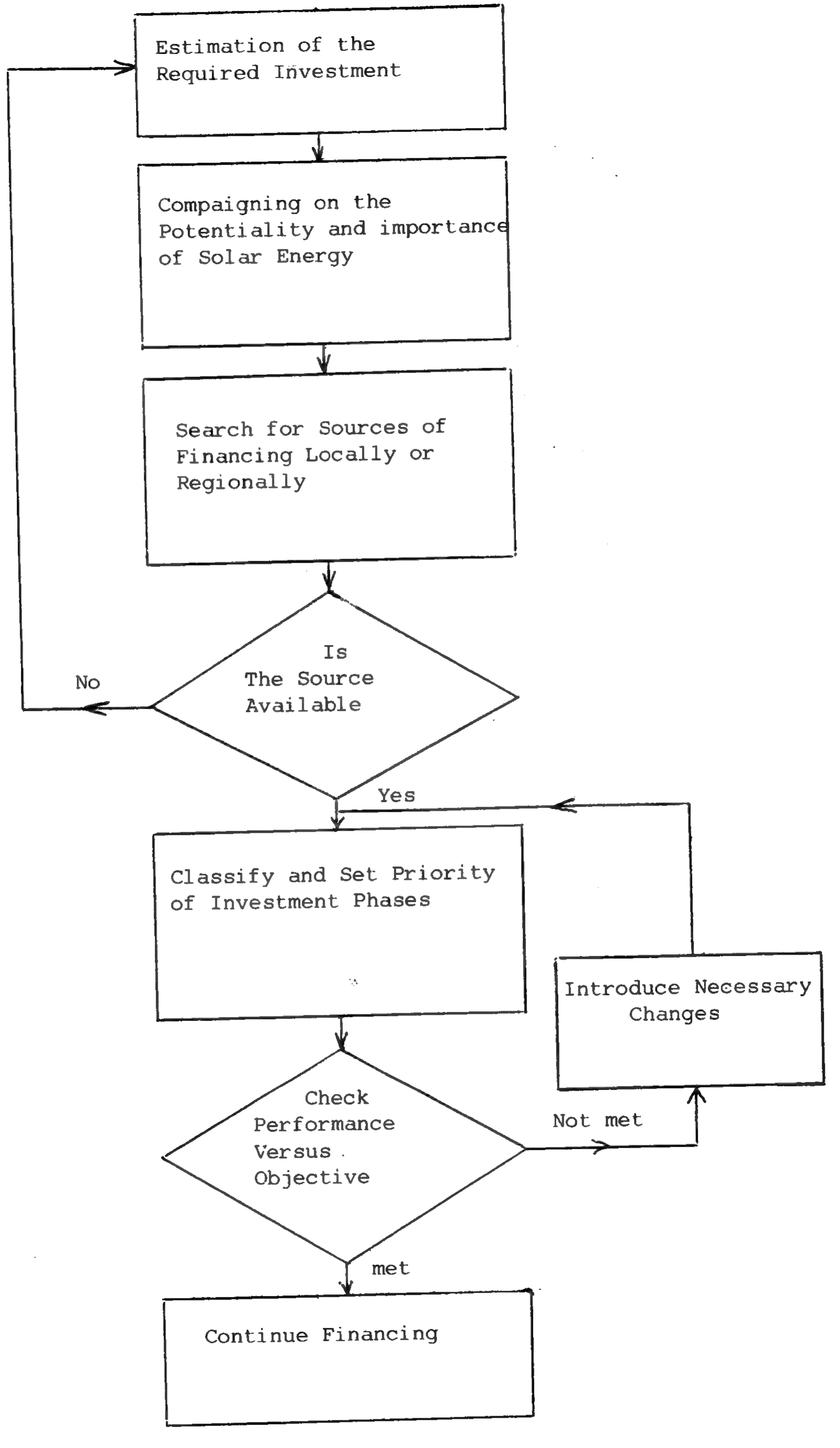

Fig. 6 : Planning Steps for Investment

4 - Classify and set priorities for investment phases according to technology acquisition, R & D development, and technical skill development.
5 - Check performance versus objectives.
6 - In case of un-satisfactory comparison, introduce necessary changes, otherwise continue financing schedule.

A flow chart representation of the planning steps is given in Fig. 6.

CONCLUSION

Transfer of the state of utilization of solar energy from a minor role to maximum reliance state is of great importance due to different factors. The transformation process can take place only if all the influencing factors reach the necesszry effective level. Planning to put the influencing factors in favour of the required change together with the over-all plan to bring the state of solar energy utilization to the desired state are given. Implementation of such parts of the plan should include some essential testing and monitoring so as to introduce necessary changes over the time span of the plan. In addition the interdependence of the influencing factors yield an accumulative effect if triggered properly will enhance the transformation process.

THE DESIGN OF ENERGY MANAGEMENT SYSTEM

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1. ABSTRACT

The desire to achieve both economic operation and good quality service make it necessary to introduce man-machine interface with computers. Energy management systems are used to achieve not only optimization and quality service, but also to provide data, control for planned maintenance, and to alarm failures in the system. This paper describes the design criteria of the hardware, and the software required for the design of a control system. Also a model of a microcomputer based energy mangement system is designed using the tabulated techniques presented in this paper.

2. INTRODUCTION

The role of digital computer for the solution of today's energy problesms is very wide. The nature of the dependence of cost and quality of service on the input variables are very complex. Typically, output variables cannot be adjusted freely, instead, they depend indirectly on other set of variables that can be adjusted. Although, the output demand is determined by the consumer and beyond the control of the supplier, the quality of the service is the sole responsibility of the supplier.

Control systems are justified if they contribute in a measurable way to the economic performance of the system.

The control systems are used to enable all the services to be supervised and remotelly controlled from one point. This can be done either by a direct transmission by wiring all necessary information from the installations to the contol center, or by transmission of the information via telecontrol equipments.

3. CONTROL SYSTEM DESIGN

The control system should be designed to adjust itself according to predetermined manner. Set points should closely be maintained and should recover from upsets and disturbances or alarm failure by digital readouts and audible alarms to draw the operator's attention.

The memory inside the controller (see Fig. 1) will enable the operator of the control system to program it from the central control room. Also in the case of computer failure the controller can stand alone, because of the intelligents mechanism provided by the memory within it.

Data are keyed in via a keybord, which are fed to the controller to react accordingly. These data might be the cost of energy, time schedules, or the quality of the services.

Although, the use of good quality components will provide high reliability, possible failures should be identified and indicated by cyclic tests within the controller. A further improvement in the system reliability can be obtained by introducing an intelligent redundancy of controllers, Fig.2 shows the added redundancy.

Information regarding the operation of the system, can be collected, stored and programmed to indicate time for maintenance, give a report of the system operation, cost of maintenance, energy price changes, or can be used as a forecasting means for future plans.

3.1 DESIGN CRITERIA

The increasing complexity of energy plants make it impossible to operate without modern computer that control and precisely optimize the continuously changing energy factors. The structure of a typical control system is shown in Fig.3. The selection of a control system should observe the following criteria [1]:

1- The operational control should be done at the controller level, leaving the mangerial control to the computer.
2- Inputs and outputs of the same nature should be grouped together to reduce interdependency between controllers.
3- The design should allow for future expansion of extra controllers.
4- Set - points comparisons should be carried at the transducers level and only signales are fed to the controllers.
5- Analog indication should be taken directly or via a separate telemetering system from the transducers.
6- Central control room should be restricted to a mimic diagram and event logger.
7- For a reliable control system:
   a- avoid new and untried equipments.
   b- where possible, purchase a system with a local support.

8- The system should be physically and electrically compatible.
9- For more flexible systems use RAM memory.
10- Memory cards should have a battery back up system (New technology systems contain non-volatile EEPROM memory chips, that is unaffected by power failures and mechanical breakdown, and proof against accidental erasure.).
11- Program changes should be restricted to authorised persons only.
12- The programs should allow for a diagrammatic representation.
13- Current status of each input and output should be provided.
14- The facility to get hard copy or store Data on tapes or diskettes should be provided.
15- The equipment should demonstrate the ability to carry out any sophisticated demands using software.

3.2. HOT WATER HEATER AS A MODEL

To illustrate these objectives we consider the problem of a hot-water heater,[2], in which the heat source may be either steam, electricity, gas or combination of the three as shown in Fig.4.

The example of the hot water heater can be used to implement some of the design critera mentioned above. Also a simple approach to help aiding the design of both hardware and software is proposed, which can easily be extended to larger scale designs.

The hardest task of the design is the list of minimum requirements of hardware and software needed for a specific control system. A good starting point will be to tabulate all connection control points and the different control functions performed by the control system . Table 1 shows this method applied to the example of water heater described above.

Table 1. List of Control Points and Functions Performed by the Control System.

Functions / Control Points	On/Off	Data Re-Cording.	Alarm Failure	Adjust-ment
Steam	X	X	X	X
Gas	X	X	X	X
Electricity	X	X	X	X
Water	-	-	-	-
a- Cold	X		X	
b- Hot	X		X	X

The table relates the connecting control points to be monitored and controlled (steam, gas, electricity, etc...), and the functions performed (on/off, Data recording, etc..).

Using table 1 we can generate table 2 which shows the control functions and the needed hardware and software to accomplish them. Fig.5 shows the complete design of the hot-water heater control system as extracted from table 2.

Table.2 List of needed hardware and softwate

Functions	Hardware	Software
1- Steam,gas and electricity.		
a- On/Off.	Computer-Controlled Switch.	Switching can take place on time set.
b- DATA Recording.	Transducers, Sensor.	Data should be stored and used as needed.
c- alarm failure.	Sensors	Priority status, so that the most urgent message is always dealt with first.
d- adjustment.	Computer-Controlled valves.	Set-points comparisons
2- Water		
a- Cold		
i- on/off	Switch	Supplied as it is consumed.
ii- alarm failure	Sensor	Switch to a reserve tank and notifiy computer.
b- Hot		
i- on/off	Switch	According to time table provided by the consumer
ii- alarm failure	Sensor	Shut down the whole system if cannot be adjusted
iii- adjustment	Computer - controlled valves.	According to cost and demand.

The design of the system is such that the controller can act on pre-programmed instruction even if the main computer is out of service. As soon as the failure is fixed the controller will update the computer on the status of the system.

To enhance the reliabilty of the system additional controller is introduced via the communication link to carry the load in case of main controller failure (refere to Fig.5).

4. CONCLUSION

The idea of automatic control in its simplest form has been described. The use of computer in control system in the area of energy management system has to meet some of the requirements mentioned in this paper.

Estimation of costs of implementing control schemes is difficult, because each design requires tailoring to particular needs. The economic viability of the control system can be evaluated by considering what would happen in its absence. The system should pay for itself in a few years. Optimization technique shows that the implementation of the control scheme is therefore economically justifiable. The criteria presented here along with the tables proposed to aid the design, should serve to form a basis for the implementation of energy management system.

5. ACKNOWLEDGEMENT

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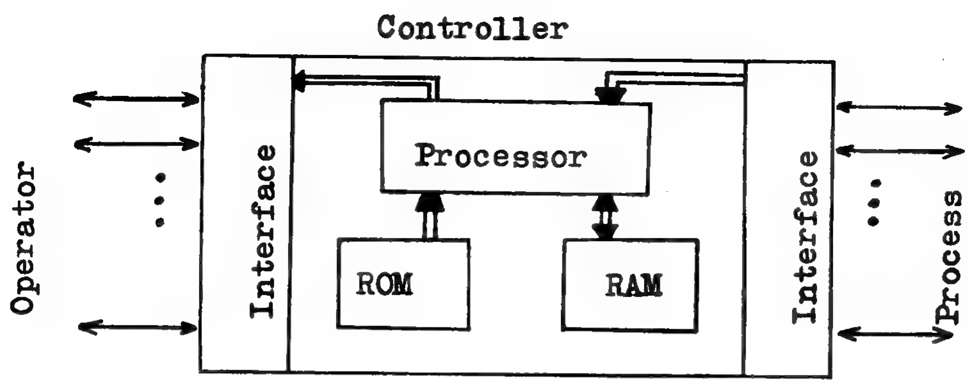

Fig.1 Typical structure of a controller

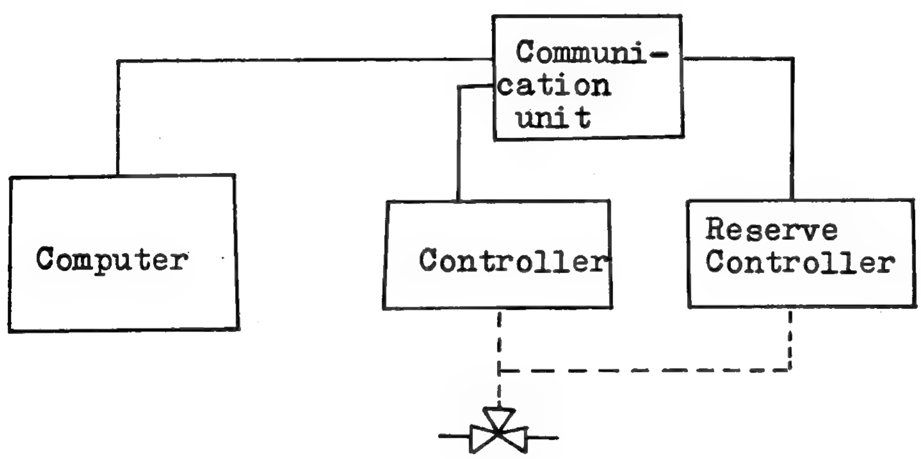

Fig.2 Reserve Controller

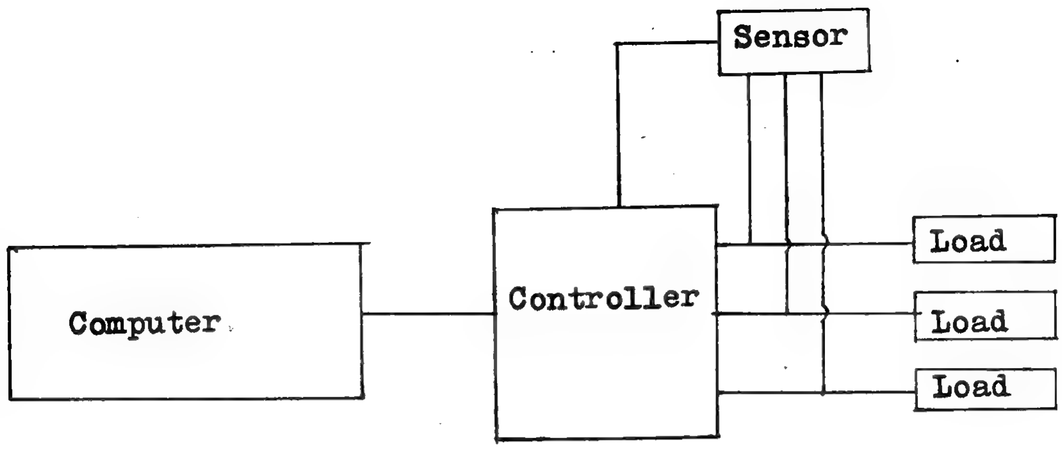

Fig.3 Typical Control system

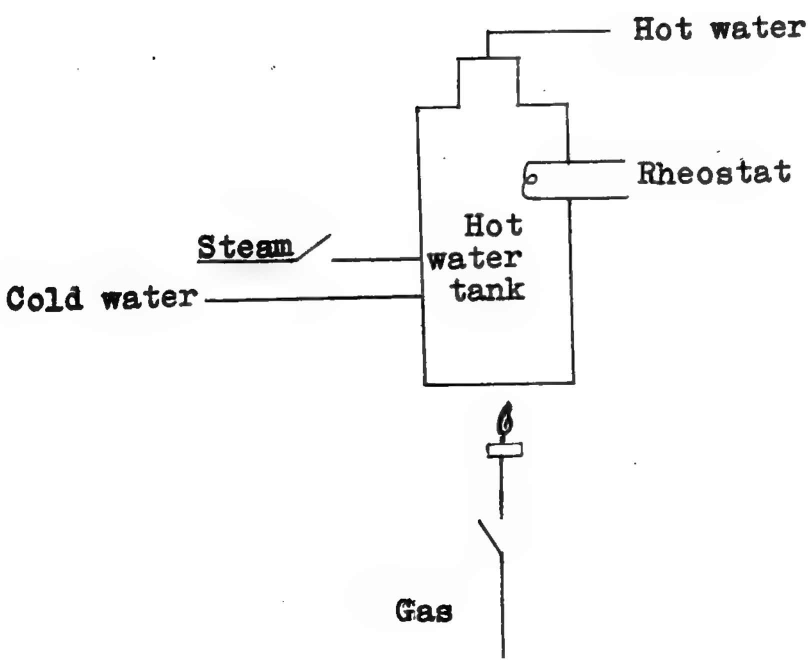

Fig.4 Hot water heater

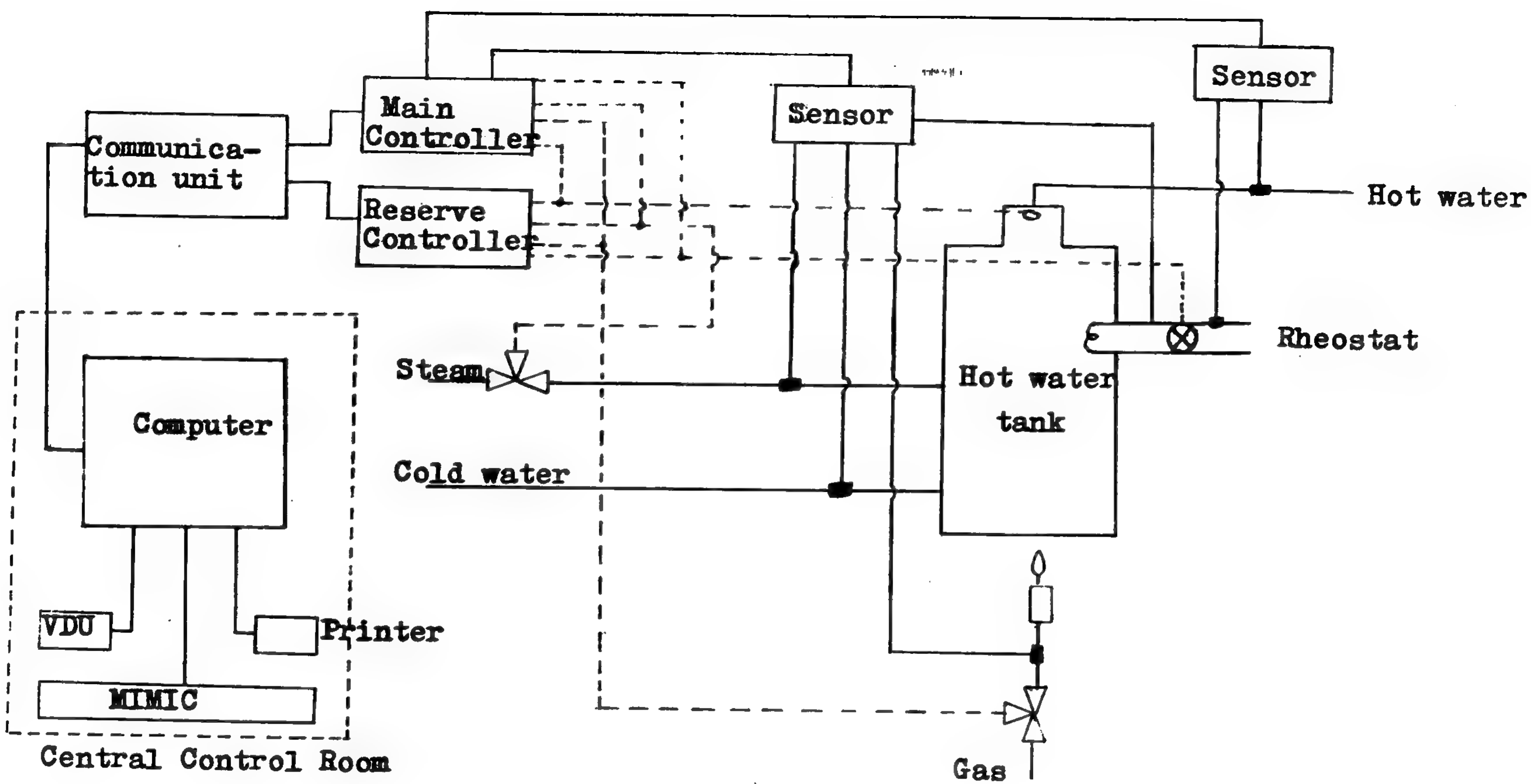

Fig.5 Hot water heater control system

THE ROLE OF CRITICAL ASSEMBLIES IN THE NUCLEAR POWER

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The critical facility at the Tajoura Nuclear Research Center (TNRC) is utilized in reactor physics research and checking the neutronic parameters of the research reactor installed at TNRC. In addition it is widely used as an educational tool for the University students and as a training facility for engineers who will be responsible for running nuclear power reactors in future.

This paper will focus on the programs that were developed to achieve the above mentioned tasks as well as the experience gained from it. Also some of the problems that were encountered and recommendations to overcome such problems will be discussed.

1 . INTRODUCTION

The critical facility of Tajoura Nuclear Research Center (TNRC) is a light water moderated reactor with a maximum power of 100 W and an enrichment of 80%. It was put in operation in Dec. 1980. This facility has been contributing to the field of nuclear power in the Jmaheria through research training and education. Separate programs were developed to carry out those mentioned tasks. Some problems were raisen during the fulfilment of those programs, some of which were solved, others remain due to outsiders contributions.

2 . RESEARCH

At the early stages of operation, most of the work performed in the critical facility was devoted to the reactor parametric study. A work program was developed to achieve that task. This program is composed of elementary experiments in reactor physics such as

2 . 1 Control Rod Calibration

The efficiency of shim and safety rods was determined using the stable period and rod drop methods. The integral rod calibration curves were plotted to be used in future work at the facility.

2.2 Reactivity worth of Different Units in the Core

The reactivity worth of either the fuel or the reflector assemblies in different core positions were determined using the control rod calibration curves.

2 . 3 Flux Mapping of the Core and Channels

Relative and absolute flux measurements were carried out in the core cells, horizontal channels and the thermal column of the critical facility using foil activation technique. The results were analyzed and tabulated to be used for further studies at the reactor.

This program took a long time due to the nature of the experiments and the precision required in such a work. After this task was finished an experimental group was established from the reactor staff to carry on reactor physics experiments of research nature.

The research program consists of a number of experiments to be performed in core, horizontal channels and thermal column of the critical assembly. The aim of these experiments was to give the experimental group the experience in initiating and conducting a research.

2 . 4 In Core Experiments

(i) Neutron temperature

This experiment was performed using the intercalibration method between black absorber (Cd) and 1/V absorber (B). The neutron temperature was determined in fuel and reflector regions.

(ii) The power calibration

Neutron activation technique was used for this investigation. The fission rate was determined and intergrated over the whole core volume to determine the power. The aim of this experiment was to calibrate the power reading instruments of the critical assembly.

(iii) Neutron spectrum

Thermal, epithermal and fast neutron flux was measured in fuel and reflector regions using foil activation technique.

(iv) Void coefficient measurements

Voids of different volumes were introduced to a critical state and their reactivities were measured. Two points were studied in this experiments The first point was determining the void coefficient reactivity of a fixed void volume in different axial position in a given core cell. The second point was determining the reactivity worth of different void volumes in a fixed axial position. However the voids introduced were not real ones.

2. 5 Horizontal Channels Experiments

Absolute thermal flux was determined in most of the horizontal channels of the critical assembly. The possibility of increasing the fast neutron flux in horizontal channel N°5 was also conducted.

2. 6 Graphite Thermal Column Experiments

(i) Relative and absolute thermal neutron flux was determined in the column using foil activation method.

(ii) Diffusion length measurement.

The thermal neutron diffusion length in graphite was determined via relative flux mapping.

The second group of experiments which are important and more rigorous than those mentioned above is being considered. These experiments include :

(i) Determination of effective delayed neutron fraction
(ii) Neutron trap experiments
(iii) Neutron temperature using lutetium foil technique
(iv) Cadmium transmission factor (Fcd) measurement
(v) Measurement and analysis of radiation and neutrons emission for irradiated fuel
(vi) Fast neutron measurement using phosphorus Polythene mixture
(vii) Diffusion length, macroscopic cross section and diffusion coefficient measurements for water and graphite

3 . EDUCATION

In addition to research , the critical facility of TNRC is used as an educational tool for the university students. The university student program is a laboratory course covering different topics in reactor physics This course is given once a year usually begins in october. Today the course consists of the following experiments, which were developed in 1983 for undergraduate students only.

3. 1 Building Up a Critical Mass

In this experiment the students ought to understand the phenomenon of accumulating a mass of fissile material. The critical mass of the reactor is determined by loading fuel assemblies one by one. In each loading , the multiplication factor is calculated and the inverse count rate curve is plotted. This curve is used for the prediction of critical mass. As a result of this experiment, the student can compare their predictions on critical mass with that actually observed.

3. 2 Reaching Criticality

After the critical mass is determined, the students should know the procedures of achieving criticality (steady state). The control rods are withdrawn in steps one by one. At each movement of the control rod , count rates are obtained and plotted versus the control rod position. Criticality positions are predicted from the extrapolation of the plotted curve to the position axis. The student ought to compare the predicted positions to the actually observed on the control panel.

3. 3 Control Rod Calibration

The regulating rod of the critical assembly is calibrated by means of the inhour equation while the shim rods are calibrated through comparison with the regulating rod. The differential and integral rod worth curves are formed to be used in coming experiments that require valves of reactivity change. Rod drop method is also used to determine the total rod worth.

3. 4 Reactivity Worth of Different Units in the Core

The aim of this experiment is to let the students understand the phenomenon of the change in criticality positions due to the change made in the core configuration. The reactivity worth of either fuel assembly or berillium units is determined utilizing the integral rod worth curve that

was established in previous experiment.

3. 5 Flux Measurement

In this experiment the students ought to measure relative and absolute neutron flux in preselected positions in the core using foil activation method. Gold foils are used to measure the absolute neutron flux while disprosium foils are used to measure the relative flux. This experiment helps the students in understanding the ways of dealing with activated foils and how to measure their activities utilizing different types of radiation measurement systems.

3. 6 Diffusion Length Measurement

The diffusion length of thermal neutrons in graphite is measured by mapping the neutron flux density of the graphite. The students performed this experiment at the thermal column of the critical facility by irradiating dysprosium foils along the axis of the graphite channel which is perpendicular to the core.

In the future the university program might be extended to cover some other experiments. The new experiments under discussion are the following.

(i) Neutron Temperature
(ii) Xenon Poisoning
(iii) Void Coefficient of Reactivity
(iv) Temperature Coefficient of Reactivity

The reactor of TNRC will also be utilized along with the critical facility in carrying out these experiments.

4. TRAINING

Besides its utilization in research and education, the critical facility of TNRC is used for training the nuclear engineers assigned to the reactor department. The training program is established for engineers who will be operators and supervisors of the reactor facilities. This program was initiated at the critical facility in 1982 and composed of safety instruction, special lectures and on-job training.

4. 1 Reactor Operators Training Program

The nuclear engineers assigned to the reactor are first instructed in radiation safety as a part of the training program. These instructions are given by the health physics group at the reactor department. The aim of these instructions is to provide the new engineers with necessary knowledge of dealing with different types and levels of radiation as well as the actions that should be taken during abnormal conditions. According to the regulations established in the reactor department, the trainees have to pass an examination on the radiation safety aspects in order to start the second stage of training. Those who fail will have to repeat the safety instruction course.

The second stage of the training program is lectures given by the critical facility and reactor staff members. These lectures include technical description of the reactor and critical facility systems, basic reactor theory, procedures of operations and other problems. This part usually takes

few month and then the trainees have to be examined before they begin the third stage in the training program.

The third stage is on-job training in the safe operation and utilization of the reactor or critical facility. The trainees have to spend one year as a reactor assistance operator under the supervision of the critical facility operators. After this period, the trainees have to pass an examination in order to work independently as a reactor operator, otherwise have to continue the on-job training.

4. 2 Reactor Supervisors Training Program

This program was proposed to prepare a reactor supervisor (shift head, controlling physicist) that can organize the operation and the maintenance of either the critical facility or the reactor in a safe way. This program is only on-job training with some notes on specific operation conditions and reactor kinetics aspects. A selected senior engineer operators are examined on the whole reactor or critical facility systems before they go on-job training. Those who pass will spend one year training under the supervision of the reactor or critical facility supervisors (shift heads, controlling physicists). After finishing the training period, the trainees have to pass another examination to permit them for an independent work as a shift head or controlling physicist.

The reactor personel gained experience from all the programs discussed in this paper. In the area of research, the reactor experimental group gained experience in initiating a research as well as a design of an experiment in addition to the adoption of different techniques used by other research institutes to our facilities. Also this research program helps the group in analyzing and discussing different ideas and topics in the field of reactor physics. On the other hand, the experience gained from the education and training programs will enable the reactor staff to conduct such programs even to students and engineers from abroad. The reactor department staff responsible for conducting the education program are well experienced in designing the same experiment differently to different students groups. The establishment of the education and training programs at TNRC have decreased the spending on training abroad.

There are some problems that were encountered during the fulfillment of all mentioned programs. The main problems that affect or sometimes delay the work are the following.

(i) The lack of certain activation foils
(ii) Processing computers are not available for counting systems
(iii) Required literature sometimes is not found at the center
(iv) Some engineering systems problems that affect the operation (electricity, water, vantilation, cooling etc)
(v) Few people are available for conducting those programs

However, some of those problems are solved while work is still going on others. We recommend that more people should be involved in such programs and that new nuclear engineering graduates should at least spend one year at the reactor department to gain experiance in the operation and to understand some of the nuclear phenomenon before they work at any other department. Advanced training and higher education is also required to the reactor staff to gain more knowledge in the field of nuclear power. In addition, exchanging visitors with different Research Centers and institutes will help in transfering technology and ideas in different topics of nuclear science.

AUTHOR INDEX

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